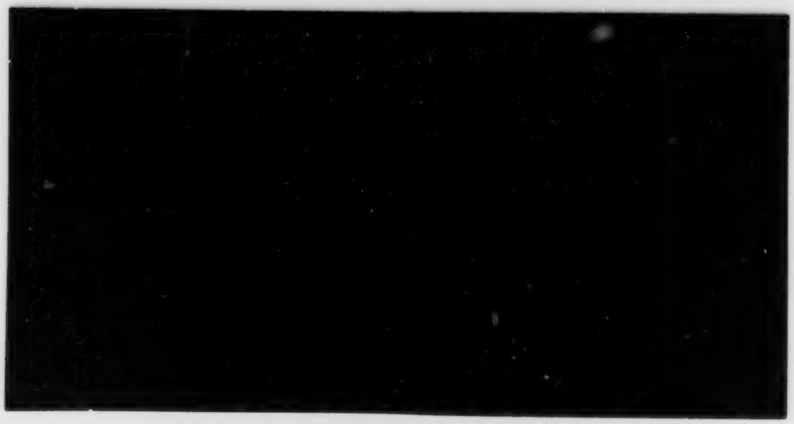
REPORT 30



SWEEP

SOIL AND WATER

ENVIRONMENTAL

ENHANCEMENT PROGRAM

PAMPA

PROGRAMME D'AMÉLIORATION

DU MILIEU PÉDOLOGIQUE

ET AQUATIQUE

Canada

Ontario

SWEEP

is a $30 million federal-provincial agreement, announced May 8, 1986, designed to improve soil and water quality in southwestern Ontario over the next five years.

PURPOSES

There are two interrelated purposes to the program; first, to reduce phosphorus loadings in the Lake Erie basin from cropland run-off; and second, to improve the productivity of southwestern Ontario agriculture by reducing or arresting soil erosion that contributes to water pollution.

BACKGROUND

The Canada-U.S. Great Lakes Water Quality Agreement called for phosphorus reductions in the Lake Erie basin of 2000 tonnes per year. SWEEP is part of the Canadian agreement, calling for reductions of 300 tonnes per year — 200 from croplands and 100 from industrial and municipal sources.

PAMPA

est une entente fédérale-provinciale de 30 millions de dollars, annoncée le 8 mai 1986, et destinée à améliorer la qualité du sol et de l'eau dans le Sud-ouest de l'Ontario.

SES BUTS

Les deux buts de PAMPA sont: en premier lieu de réduire de 200 tonnes par an d'ici 1990 le déversement dans le lac Erie de phosphore provenant des terres agricoles, et de maintenir ou d'accroître la productivité agricole du Sud-ouest de l'Ontario, en réduisant ou en empêchant l'érosion et la dégradation du sol.

SES GRANDES LIGNES

L'entente entre le Canada et les États-Unis sur la qualité de l'eau des Grands Lacs prévoyait de réduire de 2 000 tonnes par an la pollution due au phosphore dans le bassin du lac Erie. PAMPA fait partie de cette entente qui réduira cette pollution de 300 tonnes par an — 200 tonnes provenant des terres agricoles et 100 tonnes provenant de sources industrielles et municipales.

TECHNOLOGY EVALUATION AND DEVELOPMENT SUB-PROGRAM

THE RESPONSE OF SOIL MICROFLORA AND FAUNA TO SPRING PLOWING OF ZEROTILL AND PASTURE SOILS

FINAL REPORT

October, 1991

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Executive Summary

The purpose of this study is to use populations of soil organisms to contrast ecosystem stability in an undisturbed pasture with a zerotill winter wheat field. Soil organisms that were considered include soil microbial biomass, nematodes, earthworms, soil dwelling arthropods, cryptozoic invertebrates, and emergent arthropods. The pasture represents a more natural ecosystem as it is undisturbed agriculturally, and the zerotill field represents an actively managed agroecosystem.

Stability was measured by perturbing the populations of soil microflora and fauna by plowing and disking the soil, and measuring their time to return to, deflection from, and rate of return to, the ground state. Return time was faster and deflection from ground state was less in the zerotill agroecosystem than in the pasture system. These results suggest that agroecosystems are not unstable, as communities within the agroecosystem can recover from perturbation. Diversity, as measured by richness and evenness, was similar in pasture and zerotill soil for those populations for which it was determined.

Litter decomposition rate (LDR) was measured using litterbags. LDR was faster in the zerotill plowed system compared to pasture plowed, possibly because of the more rapid return of macro-invertebrates in the plowed soil. Differences in soil microbial biomass do not appear to account for differences in LDR.

Saturated hydraulic conductivity (SHC) and dry bulk density (DBD) were used to measure pore continuity. In the zerotill system, SHC and DBD were significantly higher in the unplowed soil indicating that pore continuity is much higher in unplowed soil. In the pasture system, plowed soil had a higher SHC and a similar DBD to that of

unplowed soil indicating that pore continuity is higher in plowed soil, possibly because of the destruction of roots previously plugging the pores of unplowed soil.

Water infiltration rate was found to be correlated with the number of earthworms in pasture and zerotill unplowed and plowed soils. This illustrates the importance of bioporosity in these soils.

The recommendation to plow zerotill soils every 4-5 years is put into question by this study. The soil quality indicators of earthworm number, water infiltration rate and pore continuity indicate that plowing zerotill soil may not be beneficial. Chisel plowing or ridge tillage might be acceptable intermediates.

Number of mites and richness and abundance of soil dwelling arthropods were modelled against various environmental parameters. Cropping system (pasture or zerotill), depth, and organic matter content appear to strongly influence the distribution of soil dwelling arthropods. Tillage (yes or no), water content and wet bulk density were not as important determinants. Number of mites did vary with depth over the season, numbers increasing with depth in the plowed soil, and decreasing with depth in the unplowed soil. Mites returned to the upper levels of plowed soil when temperatures and vegetational growth returned to similar levels to that of the unplowed soil.

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Chapter 1 INTRODUCTION

The Soil Community

The soil contains a very large community of microorganisms and small animals. In terms of diversity, the soil community includes representatives from all five biotic kingdoms, at least eleven animal phyla and all known types of microorganisms (Hendrix et al, 1990).

The purpose of this study is to use these soil organisms to contrast agroecosystem stability in an undisturbed pasture and a zerotill winter wheat field. Soil organisms that will be considered include bacteria and fungi considered as soil microbial biomass, nematodes, earthworms, soil dwelling arthropods, cryptozoic invertebrates, and emergent arthropods most of which pupate in the soil.

A good example of how soil animals influence soil properties are the earthworms. In one study, inoculation of deep burrowing and shallow working earthworms into no-till soil significantly increased barley plant populations, weight and depth of roots, plant height and amount of foliage. Yield was also increased in the soil inoculated with earthworms (Edwards and Lofty, 1980). Earthworms have also been found to influence soil structure. The development of favorable soil structure in a variety of parent materials has been found to be associated with high concentrations of clay-bound neutral sugars in the earthworm's feces (Shaw and Pawluk, 1986).

Water infiltration rate into soils has also been found to be related to earthworm activity. Earthworms create stable and continous macropores in soil which conduct a large volume of water from the surface into the soil (Ehlers, 1975 ;Baeumer and

Bakermans, 1973 :Lal, 1988).

Earthworms also have an influence on the rate of residue breakdown, and on plant nutrient availability. In one study, corn residue was placed on the soil surface and it was found that the residue degraded 30% faster compared to a no-worm control (Zachmann and Linden, 1989). Other studies gave similar results, soil with soybean residue and earthworms had 26% less residue left after 36 days than soil without earthworms. Soil with corn residues and earthworms had 33% less residue left than similar soil without earthworms after 36 days (MacKay and Kladivko, 1985). Earthworms promote decomposition of plant residues in many ways. Earthworms fragment and mix plant residues into the soil. Bacteria and fungi are also digested. Some fungal spores when digested are stimulated to germinate (Shaw and Pawluk, 1986b) ensuring fungal proliferation. Earthworm feces often contain more viable microorganisms than the surrounding soil (Ghilarov, 1963 ;Shaw and Pawluk, 1986b). This is likely due to litter fragmentation in the gut and the increased availability of nutrients including P, K, Ca, and Mg (Vimmerstedt and Finney, 1973). Earthworms also play an important role in inoculating soil with their feces. Actively growing microorganisms on plant residue are transported with earthworm feces to different depths and sites (MacFayden, 1968).

The decomposition of organic residue is a synergistic relationship between the invertebrate fauna and the microflora (Peterson and Luxton, 1982). Excluding invertebrates reduces the rate of breakdown of plant residue and of nutrient release (Ghilarov, 1963). This is a result of the microflora no longer being stimulated. The

microflora can immobilize significant amounts of nutrients, grazing by fauna releases these nutrients. Fragmentation of litter increases the surface area of fresh substrate necessary for the rapid growth of bacteria. Soil animals accumulate potassium and sodium and immobilize nitrogen and phosphorus. For example, up to 70% of nitrogen released during litter decomposition can be immobilized by invertebrates (Peterson and Luxton, 1982). Nitrogen is released as easily assimilable NH_4 from dead animal bodies in the spring.

The rate of movement of nutrients through the decomposition process is an important regulator of primary production. The diversity of the decomposer food web contributes to ecosystem stability by preventing excessive fluctuations in nutrient availability (Peterson and Luxton, 1982).

Stability of Ecosystems

Diversity is often assumed to be low in agroecosystems (Game Conservancy, 1990). A study in British cereal fields (Game Conservancy, 1990) has shown that 130 species of flowering plants are found in cereal fields in one study area, and that up to 1300 species of arthropods utilize cereal fields for at least part of the year. Aroecosystems are important habitats for a variety of plants and animals.

This study is concerned with the stability of two systems, an unused pasture and a zerotill winter wheat field. The pasture is undisturbed and represents a more natural

ecosystem, whereas the zerotill wheat field is an actively managed agroecosystem and is continually disturbed.

Stability, for the purposes of this study, will be defined as "the ability of a system to return to an equilibrium state after a temporary disturbance. The more rapidly it returns, and with the least fluctuation, the more stable it is" (Holling, 1973). Stability is therefore resistance to change imposed by external perturbation (Margalef, 1969). There are varying degrees of stability as the length of time required to recover from the perturbation will vary for different communities. Stability is of interest in agroecosystems because there are so many perturbations, and the ability to recover and carry on is a valuable property.

Hurd and Wolf (1974) used this definition of stability to construct a theoretical model of ecosystem stability, and used this model to design an experiment to compare the stability of systems exposed to the same stress. In this experiment stability was evaluated in terms of the response of a system to external perturbation, measured as the shift away from and return to ground (undisturbed) state. Stability was evaluated using properties of this deflection including the magnitude of deflection, the speed of response (or return time) and the rate of return to ground state.

Agroecosystems, such as the zerotill wheat field, are often assumed to be unstable. Species diversity is believed to stabilize ecosystem functional properties (McNaughton, 1977), and agroecosystems are assumed to have low diversity and therefore also low stability. Related lines of evidence include that man-made monocultures are vulnerable to pest outbreaks (Goodman, 1975) and are therefore unstable, and monocultures are

dangerously unstable because their pests have few enemy species (Murdoch, 1975).

However, some natural monocultures are considered to be stable including Spartina and bracken communities. May (1975) has indicated that man-made monocultures are unstable not because of their simplicity, but rather because they lack evolved relationships between species. This is not always the case however. The cereal ecosystem pre-dates many other more natural ecosystems in Britian such as heather moorland, coppice woodland and chalk grassland (Game Conservancy, 1990). As a result the cereal ecosystem has had more time to evolve complex relationships than some natural ecosystems.

Several studies have been completed that test stability in agroecosystems. Woolhouse and Harmsen (1987) compared the annual variability of natural and agricultural invertebrate faunas. They found that natural faunas tend to be less variable than agricultural faunas. This evidence does appear to offer quantitative support that agroecosystems are less stable than natural communities.

Suttman and Barrett (1979) found different results in a more direct test of agroecosystem stability. An application of the pesticide Sevin on an abandoned field and on an oat field had the following effects on the plant-associated arthropod community:

1. Arthropod populations in an oat field decreased more in density and biomass than in an old field following the application of Sevin.

2. The arthropod population recovered from the perturbation more rapidly in the oat field.

Suttman and Barrett's study gave mixed results, return time was faster in the agroecosystem (2) but deflection from ground state was least in the old field (1), hence it is hard to draw conclusions about stability.

This study tests the stability of agroecosystems using the soil microflora and fauna as indicators of the state of the ecosystem. Plowing and disking are used as the perturbation. The deflection from ground state and the return time of abundance, richness and eveness of these populations will be compared in pasture and zerotill soil to test stability.

Hypothesis

The null hypothesis being tested is that there is no difference in the stability of old pasture and zerotill winter wheat ecosystems. Under this null hypothesis, stability will be considered using return time, amount of deflection and the rate of return to ground state (amount of deflection/ return time).

Chapter 2 Materials and Methods

1. Site and trapping/ collecting methods

a) Site

The research was conducted at a farm eight kilometres south of Mount Forest, Ontario. The soil was a Harrison loam and the two agroecosystem types, pasture and zerotill were approximately 50 m from each other on level, well drained soil. Soil pH was approximately 7.5 at 0-20cm depth in both cropping systems. The pasture was unused and has not been disturbed agriculturally for more than five years. The zerotillage field has been under zerotillage for five years and has been in a two year corn, two year grain and two year legume rotation, 1990 being the second year of grain (winter wheat) underseeded with red clover (Table 1).

The zerotilled and pasture soil sites were each divided into eight 10 m X 10 m plots. Four plots from each site were randomly assigned to be plowed, and moldboard plowing and disking was completed on May 26, 1990. Depth of plowing ranged from 16-19 cm, most commonly 17 cm. Field sampling took place from late April to mid November, 1990, to sample populations before and after disturbance by plowing.

In this study, pasture soil and zerotill soil are cropping systems, and plowing is the treatment. There are therefore unplowed and plowed pasture plots, and unplowed and plowed zerotill plots. Plowed zerotill soil, by definition, is soil that has undergone no cultivation for the past five years and was spring plowed on May 26, 1990 as a treatment.

Table 1 Cropping history of the zerotill field over the past 6 years.

Year	Crop	Herbicide	Fertilizer	Yield
1985	Conventional tillage corn	Atrazine 2L/acre	urea 120 lbs/acre	126 bu/a
1986	Zerotill winter wheat	none	urea 100 lbs/acre	65 bu/a
1987	Zerotill corn silage	Atrazine 5L/acre	urea 120 lbs/acre	2 ton/a
1988	Zerotill corn silage	Banvil 1L/acre	urea 120 lbs/acre	2 ton/a
1989	Zerotill barley	2,4-D 1.5L/acre	urea 80 lbs/acre	80 bu/a
1990	Zerotill winter wheat with clover	none	none	60 bu/a

b) Nematodes

Soil nematodes were sampled by taking 2 cm by 20 cm cores, liquefying the sample in 500 mL of water and sieving the slurry through a nest of number 20, 60 and 400 meshes (Altman ,1982). The number of nematodes was counted in duplicate samples under 40X magnification. Two soil samples were taken per plot over the entire field season (see Figure 1 for sampling intervals).

c) Earthworms

Earthworms were sampled using a combination of formalin and hand sorting methods. Formalin (25 mL) was added to 4.5 L of water and sprinkled over 0.45 square metres (Raw ,1959). Any earthworms that came to the surface were collected and after 30 min., the soil was excavated to a depth of 20 cm and the rest of the earthworms were found by hand sorting. This combined method results in a higher yield of earthworms collected (Neave, unpublished results). One sample was taken per plot over the entire field season (see Figure 3 for sampling intervals).

d) Cryptozoic invertebrates

Pitfall traps were used to sample the cryptozoic fauna. One 12 cm diameter pitfall trap was sunk to ground level in all plots. After July 4, half of these traps were removed because of concerns about removal of too much of the populations (Table 4 gives the sampling interval). These pitfall traps are behavioural in nature, any invertebrates whose path is intercepted by these traps, fall into them, and are preserved in ethylene glycol. Three community parameters were calculated for each "catch", abundance, richness and eveness. Abundance is defined as the number of individuals

per catch, richness as the number of species per catch and eveness as the inverse of Simpson's index ($1/\Sigma p_i^2$) divided by Shannon's index $-\Sigma p_i \ln p_i$ (Hill ,1973). Pitfall traps were emptied at regular intervals over the entire field season. The similarity of paired pitfall traps in unplowed and plowed soils was also calculated using Jaccard's similarity index = $j/(a+b-j)$ where j= the number of species common to the two samples, and a and b are the total number of species in each sample (Southwood, 1987).

Cryptozoa boards were also used to sample the cryptozoic fauna. Three 30cm X 30cm painted plywood boards were placed in each plot and at regular intervals the organisms which hid under the boards during the day were counted (Cole, 1946). Abundance and richness were calculated for each plot, as was the abundance of the most common species.

e) Mites and springtails

The soil dwelling mesofauna (the mites and springtails) were sampled using a modified Tullgren funnel or high gradient extractor similar to that of Norton (1982). Some soil insects and larvae were also extracted. Two soil cores (4.8cm x 5cm) were taken per plot to a depth of 15 cm and placed into the extractor. Light intensity above the cores was gradually increased, thereby increasing temperature and decreasing soil moisture from the top of the core down. The mites and springtails moved down the core and fell into ethylene glycol, and were later counted and identified under a microscope. Soil water content, temperature, bulk density and organic matter content was determined for each mite sample. These values were used in a multiple regression model to determine which variables affected mite numbers.

f) Microbial Biomass

Soil bacterial and fungal biomass was determined using the fumigation extraction method. Biomass Carbon (C) and Nitrogen (N) were determined using the Ninhydrin-N technique (Joergensen and Brookes, 1991). Soil samples were taken from the plots at 0-10 cm and 10-20 cm depth, and each sample was seperated into four 10g samples (sampling intervals are shown in Figure 5). Soil water content was determined at this point. Two 10g samples were extracted in 0.5M K_2SO_4, and two samples were fumigated under vacuum pressure with ethanol-free chloroform for 24 hours. These samples were subsequently extracted with 0.5M K_2SO_4. The difference between fumigated and unfumigated soil extractions is what the lysed microbial cells have added to the extract. The soil extracts were frozen at -18°C until analysed. Ninhydrin-N was determined spectrophotometrically and Biomass C was calculated as 21 X ninhydrin-N and Biomass N was calculated as 5 X ninhydrin-N.

Soil biomass P was determined similarly to biomass C and N. 0.5 M $NaHCO_3$ was used as the extractant. Soil samples were broken up into seven subsamples, two were extracted with $NaHCO_3$ immediately (a), two were fumigated with no-alcohol chloroform for 24 hours and then extracted (b), two had the equivalent of 25 ug P added to them and were then extracted (c) (Brookes et al, 1982). The seventh subsample was used to determine water content. The extract-soil mixture was mixed, filtered and the extract was then added to a mixed reagent containing ammonium molybdate (Murphy and Riley, 1962). The phosphomolybdenum complex formed upon mixing was then measured in a spectrophotometer at 882 nm to determine phosphorus content. Biomass

P content of the soil is then calculated using the following formula.

Biomass P = 25(b-a)/ 0.4(c-a) ug P/ g oven dry soil (Brookes et al, 1982).

Soil biomass C to P ratios were calculated by dividing biomass C by biomass P at the same sample date.

g) Emergent invertebrates

Emergence traps were used on all plots to capture invertebrates that emerge as adults from the soil after pupating. These traps were 0.5 min area and consisted of a wooden frame enclosed by spray-painted unbleached cotton. At the top of the trap there was a hole leading to a funnel which had a plastic container attached to it. The plastic containter contained antifreeze and had a tight fitting lid so that any invertebrates that flew up through the funnel would have difficulty flying back out, and would instead fly into the antifreeze and be preserved. Traps were emptied once a week until the material started to disintegrate.

2. Physical measurements

a) Litterbags

Four pairs of litterbags were placed in all plots at the surface and at 10cm depth in May. These litterbags were nylon mesh and were filled with alfalfa hay. Ten holes were cut in each bag to allow earthworm entry and exit. At intervals over the summer, one pair of litterbags was dug up from each plot and the change in dry weight per day determined. Only plant material that was large enough to remain within the mesh was weighed.

b) Saturated hydraulic conductivity

Saturated hydraulic conductivity (saturated flow rate of water through soil) at 20 cm was determined for each plot in late August using a Guelph permeameter (SWEEP equipment). Two determinations were done per plot and nematode, mite and springtail, and earthworm numbers were also determined in adjacent soils. These faunal populations were correlated with saturated hydraulic conductivity.

c) Water infiltration rate

Water infiltration rate was measured using a Guelph permeameter in late August twice in each plot. A 16 cm diameter pipe was driven perpendicularly into the soil to a depth of 10 cm. Water was ponded to a depth of 7 cm inside the pipe and the Guelph Permeameter used to measure the amount of water entering the soil over this area enclosed by the stovepipe. Infiltration rate was then correlated with earthworm abundance.

d) Percent cover

The percent cover of plant species in pasture and zerotill soil was estimated, and Dominance was calculated for each plot. Dominance was determined by dividing the percent cover of the most common plant by the percent cover of all plants.

e) Soil mixing

The amount of soil mixing attributable to moldboard plowing and disking was measured through the addition of KCl to the soil surface prior to plowing and disking. 2.5 kg of KCl was added to two 1 m^2 plots that were 1 m apart from each other in a line perpendicular to the direction of plowing and disking. One 1 m^2 plot (no KCl) was

established beside each of these plots. Four 20 cm soil cores were taken in the two plots with added KCl (in row) and four cores in the plots without added KCl (out of row). These cores were divided into 5 cm increments. The moldboard plow was then pulled through these plots and further samples were taken, both in the original plots and further on in the plows path. Further samples were taken similarily after the area was disked. The 5 cm soil cores were then shaken in a 10:1 water dilution, and the filtered extract was analyzed for chloride ion content using the TrAAcs 800 autoanalyzer (Tel and Heseltine, 1990).

Chapter 3 Stability of Pasture and Zerotill Systems

Three parameters were used to assess stability in pasture and zerotill ecosystems: return time, deflection of the population parameter from ground state, and the rate of return to ground state.

Measurement of return time

Return times of microfloral and faunal populations were calculated using two methods.

In the first method (A) a population was considered to have returned to ground state when the disturbed and undisturbed populations (paired plots) were within 15% (arbitrary and predetermined) of each other for two consecutive samplings. This definition avoids the potential problems caused by oscillations and seasonal variations of the disturbed population. The first sampling time of this pair is then chosen as the return time. Mean pasture and zerotill return times were compared statistically using t-tests. The last date of sampling was chosen for statistical comparison if paired plots did not have a return time for a particular population. This procedure underestimates the mean return time for that population, because the return time would probably be longer than this assigned value.

The advantage of this method is that it depends solely on the populations of an unplowed and plowed paired plot returning to within 15% of each other (15% was

chosen because previous work in this field suggested populations were highly variable). Each paired plot is evaluated separately and its return time is not dependent on the population of animals in other plots. Differences in return time between pasture and zerotill soils can also be tested directly, using a t-test.

The second method (B) of calculating return time is to use a t-test to determine if there is a significant difference between undisturbed and disturbed populations. The four differences between paired plots are used in the t-test. If there is a significant difference, the disturbed populations have not returned, and when there is no significant difference for two consecutive sampling periods, the disturbed population is considered to have returned.

The third method (C) of calculating return time is very similar to the second, except the Mann-Whitney U test is used in place of the t-test if the assumptions of the t-test (equal variance and normal distribution) were not met. The Mann-Whitney U test was used as it is an effective method for comparing small sample sizes.

The advantages of methods B and C are that they test whether or not the plowed soil's animal population is significantly different from that of the unplowed soil's animal population, and do not rely on a predetermined difference such as 15%. For both the second and third methods, a difference in return time between pasture and zerotill cannot be compared statistically. However, as return times are dependent on statistical similarity between unplowed and plowed plots, any difference in return time between pasture and zerotill is valid.

Earthworm populations were not considered because their were no/very few

active earthworms after the time of perturbation due to rheir seasonal trends.

Return times

Six populations of organisms returned significantly faster in the zerotill soil, and no populations returned significantly faster in the pasture soil using Method A. Three populations did not return in the sampling period, and two other populations did return but there was no significant difference between their return time in pasture and zerotill soil.

Using Methods B or C, four populations of organisms returned faster in the zerotill soil, and none returned faster in the pasture soil. In three populations, there was no difference in the return time between pasture and zerotill soil.

Measurement of Deflection

Deflection is the amount a plowed soil's population parameter is in/de-creased after plowing compared to the unplowed soil's population parameter (ground state). It is measured as the percentage difference between unplowed and plowed soil's populations at the first sampling date after plowing.

The deflection of the soil microflora and fauna's population parameters is shown in Table 2. Each deflection is an average of four values. A t-test was performed to determine whether deflection in pasture and zerotill soils was significantly different.

Table 2 Deflection away from ground state for soil microflora and fauna population parameters.

Population parameter	Deflection Zerotill	Pasture	significance of t-test
Biomass C,N 0-10	53%	45.7%	n.s.
Biomass C,N 10-20	42.3%	38.1%	n.s.
# of nematodes	26.6%	37.0%	<0.05
# of slugs	100%	100%	n.s.
Total # of animals	68%	65%	n.s.
pitfall abundance	42%	139%	<0.05
pitfall richness	58%	12%	n.s.
pitfall eveness	11%	63%	<0.005
Em trap abundance	43%	55%	n.s.
Em trap richness	20%	26%	n.s.
Em trap eveness	13%	12%	n.s.

Only 3 pairs of pasture and zerotill deflections were significantly different, number of nematodes, and the abundance and eveness of cryptozoic invertebrates captured in pitfall traps. In all three cases, deflection away from ground state was greatest in the pasture soil.

Measurement of rate of return to ground state

Rate of return to ground state of the disturbed population was measured by calculating the slope of recovery, that is dividing the deflection away from ground state by the return time.

The rate of return to ground state of plowed pasture and zerotill soil population parameters are shown in Table 3. Rate of return was faster in zerotill soil for soil biomass at 0-10 and 10-20cm, number of slugs, number of sowbugs and total number of animals found under cryptozoa boards. Rate of return was faster in zerotill soil for number of nematodes, and the abundance, richness and eveness of the cryptozoic invertebrate population caught in pitfall traps.

Table 3 Return time (Method B or C except Method A for pitfall traps), deflection away from ground state and rate of return to ground state for soil microflora and fauna population parameters.

Population parameter	Return time (Days)		Deflection (%)		Rate of return (%/day)	
	Pasture	Zerotill	Pasture	Zerotill	Pasture	Zerotill
Biomass 0-10	2	9	53	45.7	26.5	5.1
Biomass 10-20	2	2	42	38	21.2	19.1
# of nematodes	9	19	27	37	1.40	1.95
# of slugs	35	95	100	100	2.86	1.05
# of sowbugs	39	79	92	100	2.35	1.27
Total #	39	95	68	65	1.74	0.68
P'fall abund	46 *	102 *	42	139	0.91	1.36
P'fall rich.	86 *	11 *	58	12	0.67	1.08
P'fall even.	38 *	156 *	11	63	0.28	0.41
Em abundance	-	-	43	55	-	-
Em richness	-	-	20	26	-	-
Em eveness	-	-	13	12	-	-

Chapter 4 Comparison of Population Seasonal Trends and Soil Physical Properties

1. Abundance of Nematodes

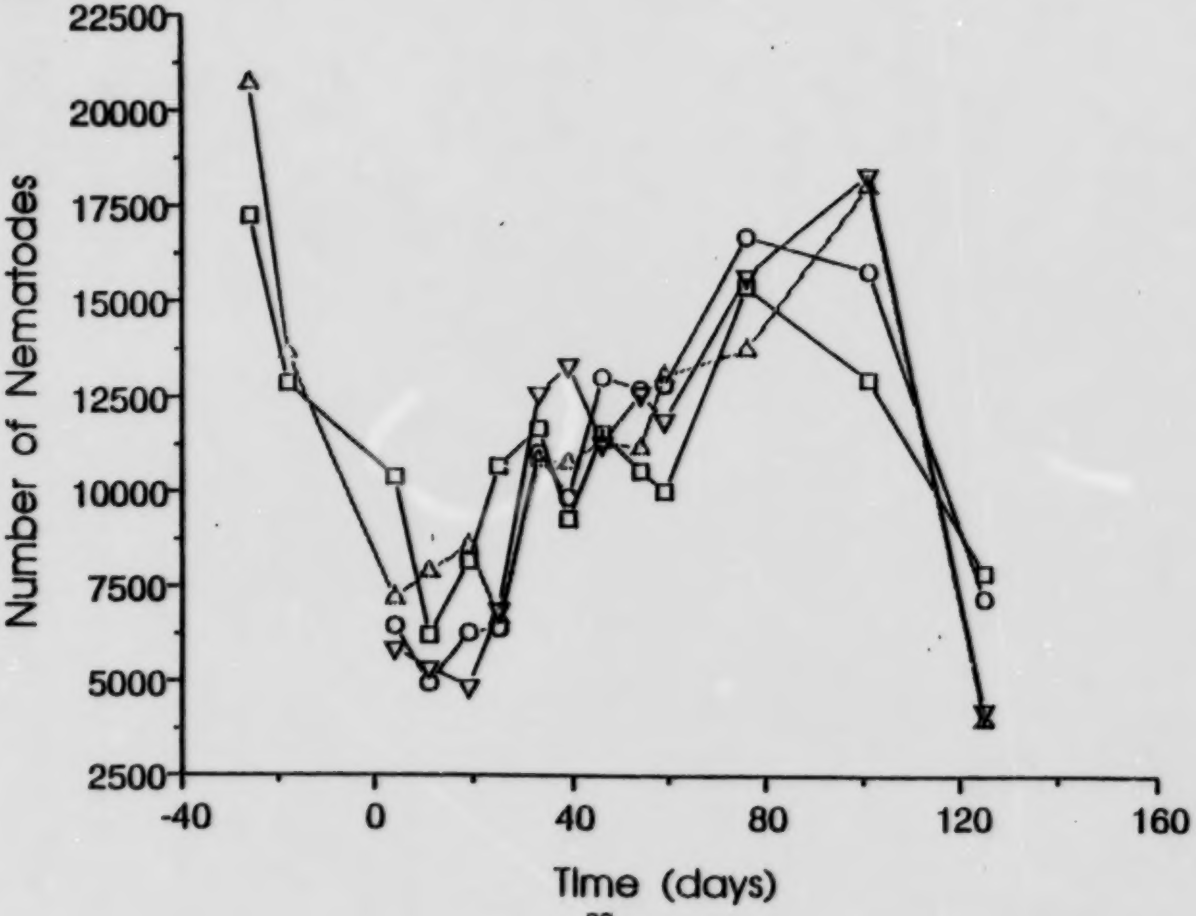
The seasonal trend in number of nematodes in unplowed pasture and zerotill soils was similar. The number of nematodes was high in early April, fell to a low in June and then rose until September, falling again in late September. Plowing pasture and zerotill soils decreased the number of nematodes initially, but the general seasonal trend was similar to that of unplowed pasture and zerotill soils (Figure 1).

The number of nematodes was initially higher in zerotill than in pasture soil, but population size was roughly equal for the majority of the season. Towards the end of the season nematode number was higher in pasture soil (Figure 1). At its peak, nematode number was around 27,000,000/m^2 and 33,000,000/m^2 in pasture and zerotill soils respectively.

2. Earthworms

In zerotill soil the number of earthworms in unplowed plots was low in early April (Figure 2). Numbers increased slightly in May, were very low in June and July and started to increase in August, rising to a maximum in November. The number of earthworms in plowed zerotill plots was very low well into August and then began to increase following the pattern of the unplowed plots. By November, the numbers in plowed plots were closely approaching those in unplowed plots. A similar trend was observed in the pasture soil (Figure 2) except that the number of earthworms was

Figure 1 Number of nematodes in unplowed pasture (□), plowed pasture (○), zerotill unplowed (▵) and zerotill plowed (▿) soil at times before and after plowing. Time zero is the date of plowing (May 26, 1990). (This legend applies to all successive figures.



higher, and the numbers in plowed plots did not approach as closely the numbers in the unplowed soil. By the end of the sampling season, the number of earthworms in unplowed pasture soil was more than double that in unplowed zerotill soil. In unplowed pasture soil there were 477 earthworms/m^2 on average and in unplowed zerotill soil there were 212 earthworms/m^2.

The seasonal trend of earthworm mass was similar to that of earthworm number for both pasture and zerotill soils. The mass of earthworms was higher in pasture soils, and the masses came closer to returning to that of the unplowed soil at the end of the season in the zerotill soil. Earthworm mass was 240 g/m^2 and 160 g/m^2 at the end of the sampling season in pasture and zerotill soils respectively (Figure 3).

3. Cryptozoic invertebrates

The abundance of cryptozoic invertebrates was generally low in the spring, high in the summer and low again in late fall. In both pasture and zerotill soils, the abundance in plowed soil generally followed the trends of the unplowed soil. However, abundance was higher in zerotill soils than in pasture (Figure 4).

The species richness of cryptozoic invertebrates caught in pitfall traps showed a similar trend to abundance in both pasture and zerotill soils. Richness was generally similar in pasture and zerotill soils (Figure 5).

Eveness of this soil community was relatively constant and similar over the season for both pasture and zerotill soils, although it oscillated frequently. The plowed soil of zerotill and pasture followed the same seasonal trend as the unplowed soil (Figure 6).

__Figure 2__ Number of earthworms recovered from pasture and zerotill unplowed (□,▵) and plowed (o,▿) soils at times before and after plowing.

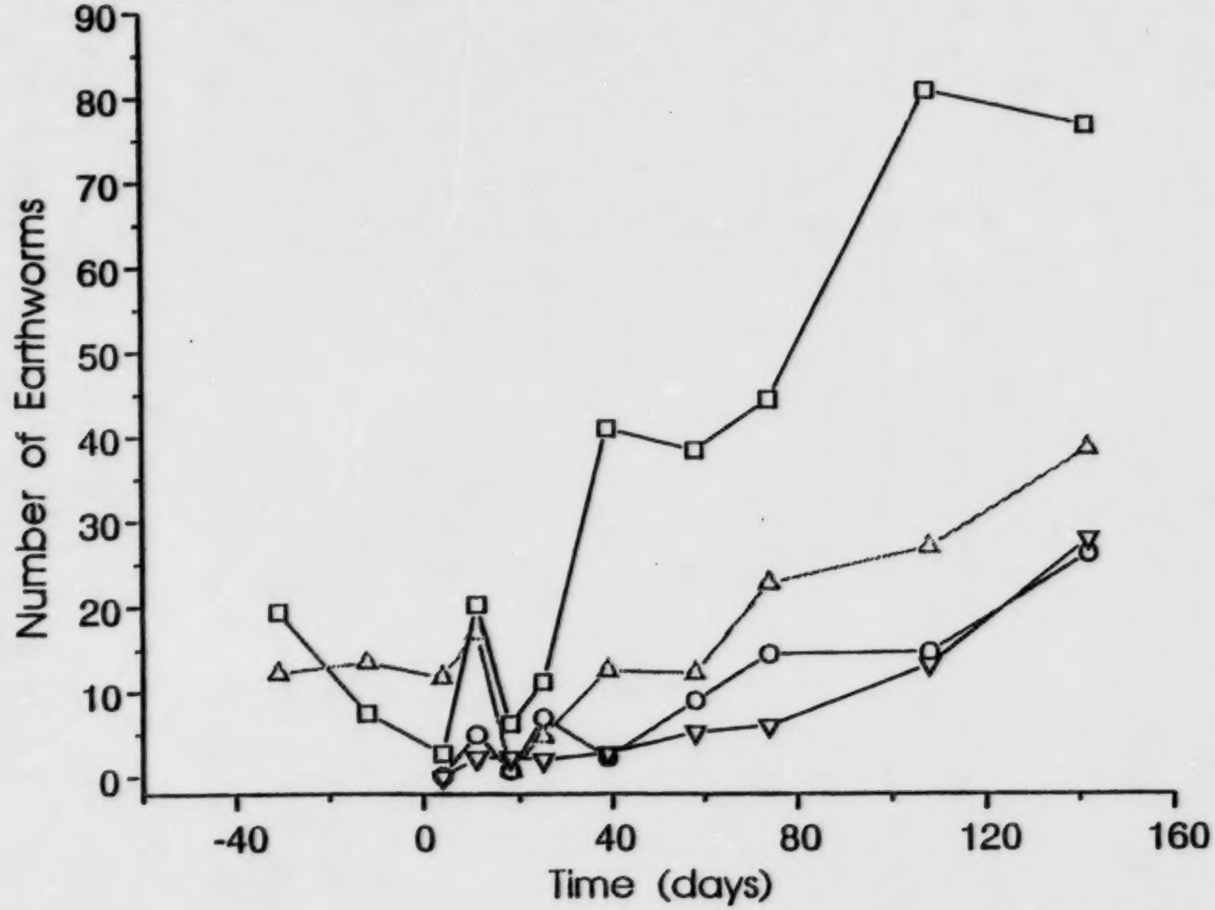


__Figure 3__ Mass of earthworms found in the pasture and zerotill unplowed (□,△) and plowed (○,▽) soils before and after plowing.

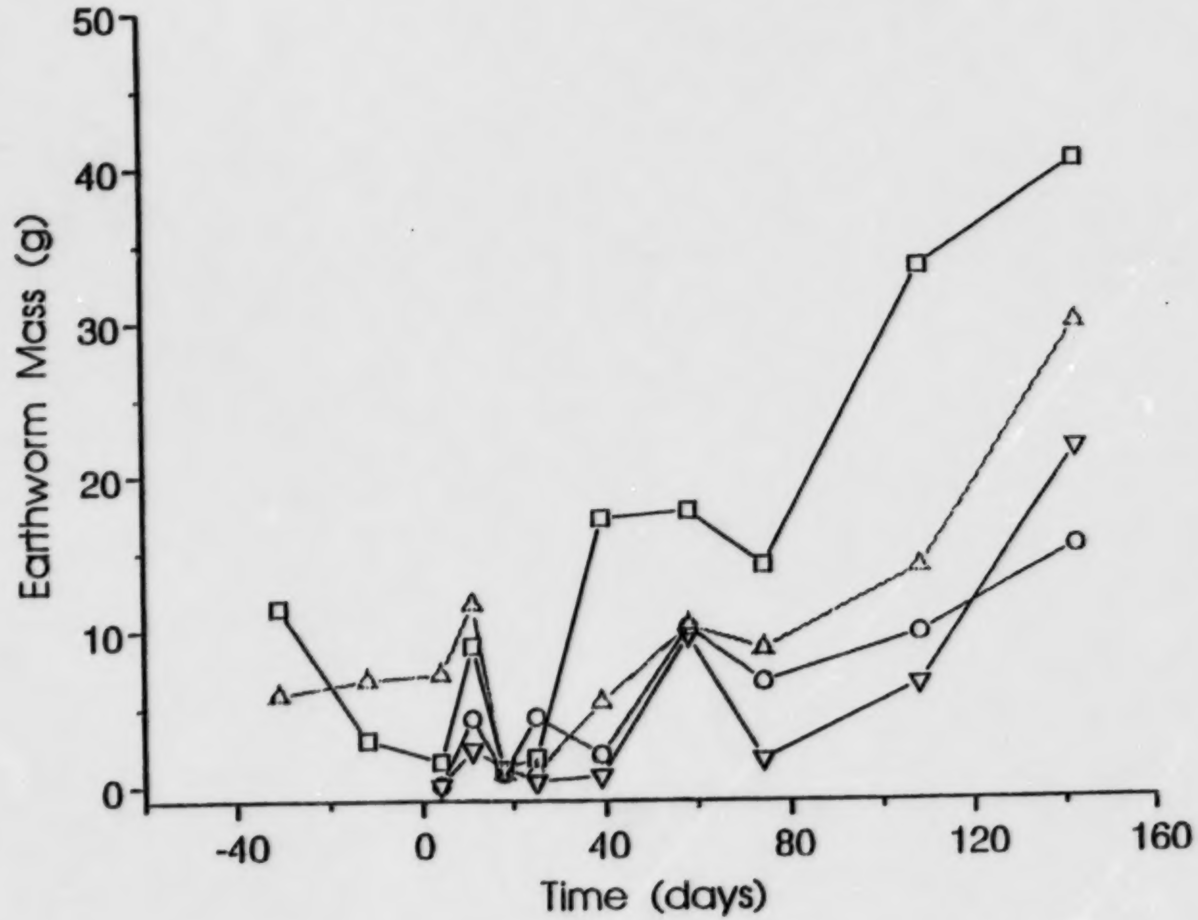


Figure 4 Abundance of organisms captured in pitfall traps in pasture and zerotill unplowed (□,▵) and plowed (○,▿) soils before and after plowing.

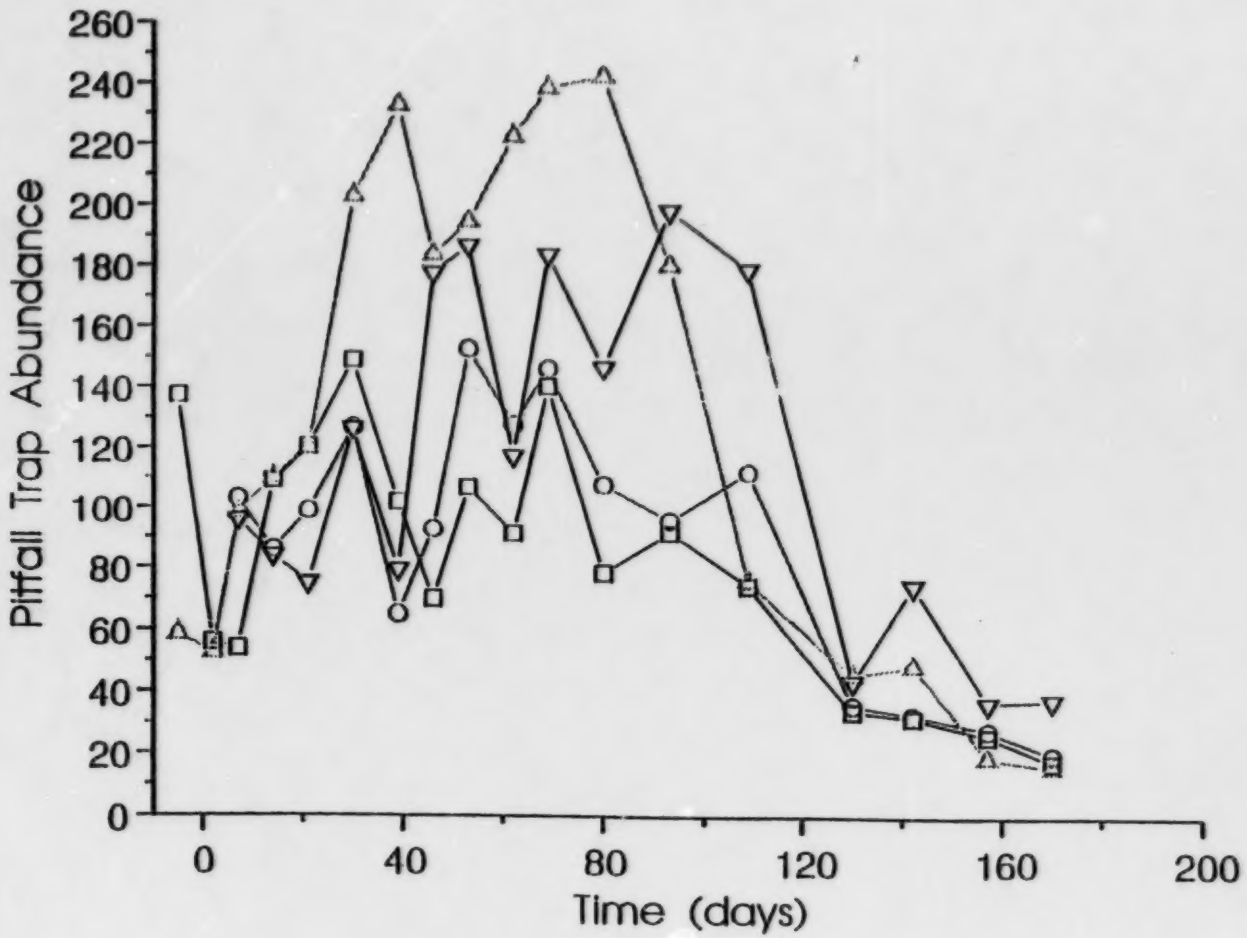
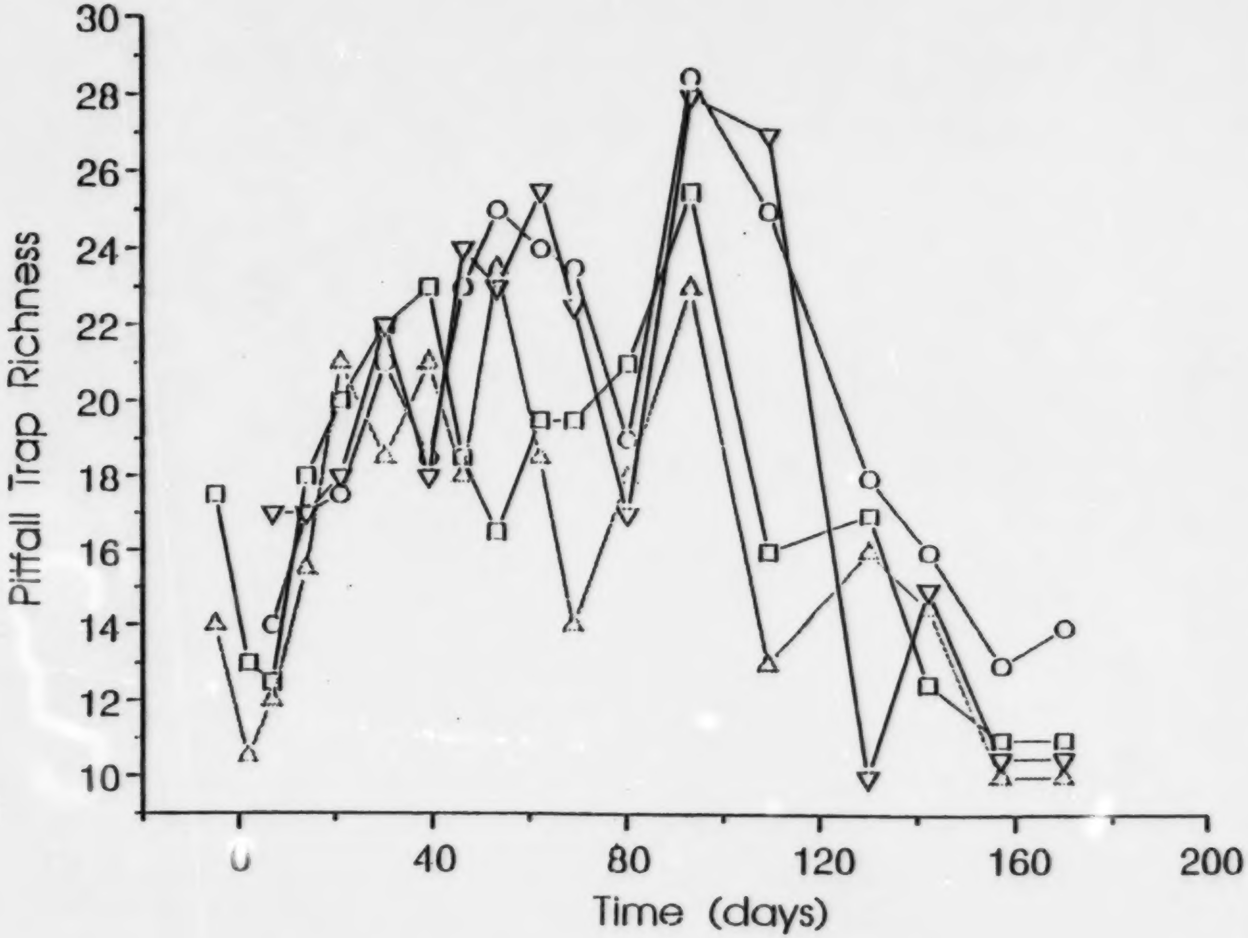
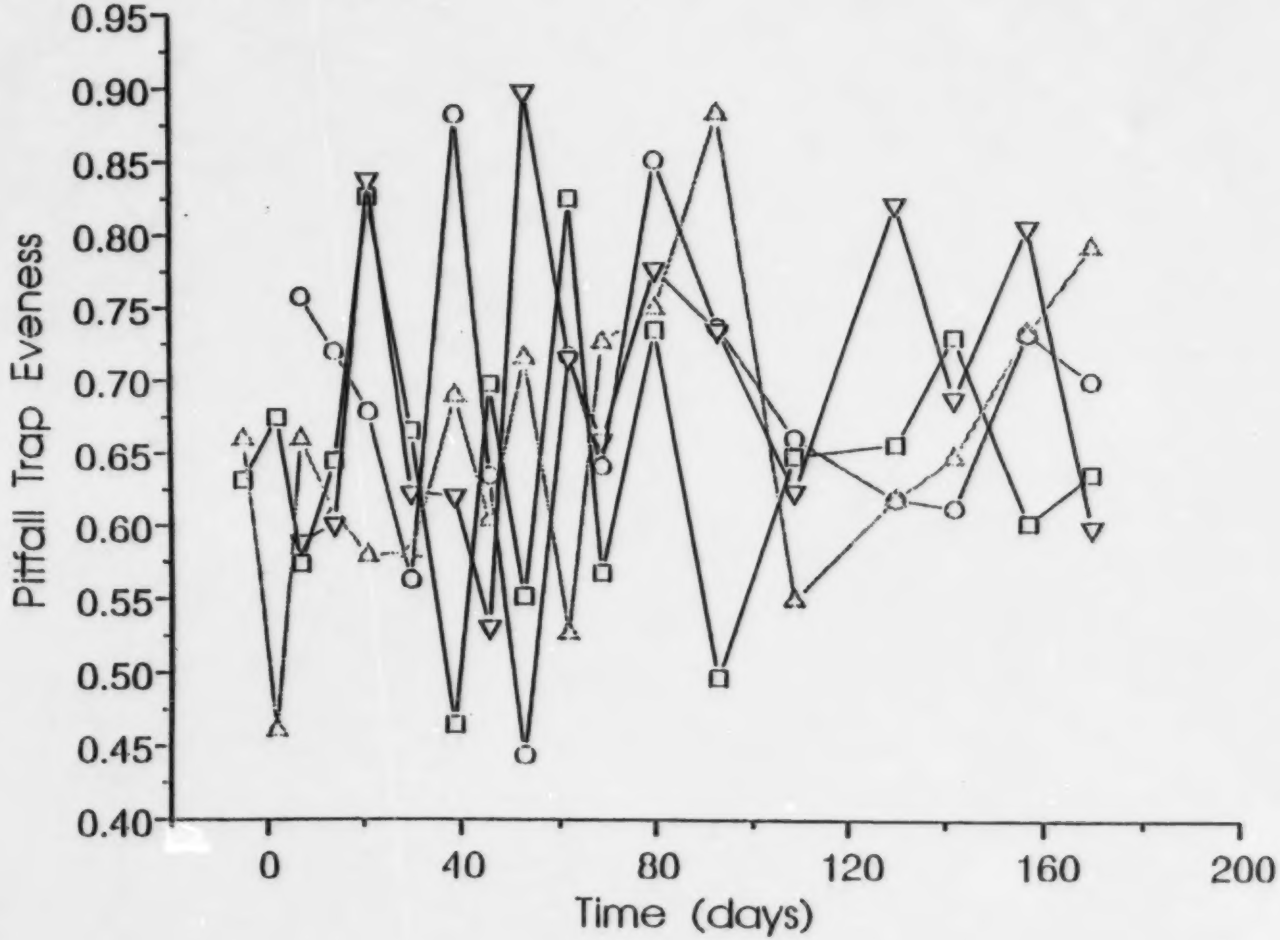


Figure 5 Richness of organisms captured in pitfall traps in pasture and zerotill unplowed (□,△) and plowed (○,▽) soils before or after plowing.



<u>Figure 6</u> Eveness of the community of organisms captured in pitfall traps in pasture and zerotill unplowed (□,▵) and plowed (○,▿) soils before and after plowing.



In both pasture and zerotill soil, the number of animals found under cryptozoa boards in unplowed plots increased throughout the summer, peaking in August-September and declining in the fall. The number of animals was substantially lower in the plowed plots of zerotill and pasture soil and increased gradually over the summer to match populations in the unplowed soils.

The abundance of animals captured in pitfall traps is shown in Figure 4. Abundance was generally higher in zerotill soils, especially when populations were at their peak in mid-late summer. Species richness of animals captured in pitfall traps (Figure 5) and eveness (Figure 6) of populations were very similar in pasture and zerotill soils throughout the sampling period.

The occurrence of different animal taxa in zerotill and pasture plowed and unplowed soils is shown in Table 4. Taxon occurrence was very similar in all four plot types, ranging from 44 to 48 taxa. The dominant species captured in pitfall traps including crickets, sowbugs, earwigs, slugs and others were found in all four plot types. Differences in occurence generally occurred with species that were rarely captured.

Jaccard's similarity index (based on community richness) was determined for each plowed-unplowed paired plot and for unplowed-unplowed paired plots in each cropping system (Table 5). The similarity values calculated for unplowed-unplowed plots and the similarity values calculated for unplowed-plowed plots were close to each other over the entire sampling period. There were no consistent differences between similarity values. Only towards the end of the sampling period did the values begin to diverge in zerotill and pasture soil.

Table 4 Occurrence (X) and absence (-) of cryptozoic invertebrate taxa in pasture and zerotill unplowed and plowed soils. A list of common and scientific names of these taxa is provided in Appendix I.

Species/ taxa	Pasture unplowed	Pasture plowed	Zerotill unplowed	Zerotill plowed
slugs	X	X	X	X
Lumbricus	X	X	-	-
sowbugs	X	X	X	X
Entomobryinae	X	X	X	X
Acrididae	X	X	X	X
Gryllidae	X	X	X	X
earwigs	X	X	X	X
Leafhopper	X	X	X	X
Delphacidae	-	X	-	-
Nabidae	-	X	X	X
stink bug	-	-	X	-
aphid	X	X	X	X
Silphidae A	X	X	X	X
Silphidae B	X	X	X	X
Staphylinidae	X	X	X	X
Nitidulidae	X	X	X	X
Carabid A	X	X	X	X
Carabid B	X	X	X	X
Carabid C	X	X	X	X
Carabid D	X	X	X	X
Carabid E	X	X	X	X
Carabid F	X	-	X	X
Carabid G	X	X	X	X
Carabid H	-	-	X	-
Cantharidae	-	-	-	X
Coccinellidae	-	X	X	X
Curculionidae	X	X	X	X
beetle larvae	X	X	X	X
Moth	-	X	-	-
Diptera A	X	-	-	X
Diptera B	X	X	X	-
Diptera C	-	X	-	-
Sciaridae	X	X	X	X
Mycetophilidae	X	-	-	-
Phoridae	X	X	X	X
Empididae	-	-	X	X
Syrphidae	-	X	X	X
Drosophilidae	-	-	-	X
Calliphoridae	X	X	X	X
Anthomyiidae	X	X	X	X
Braconidae	X	X	X	X
Formicidae A	X	X	X	X
Apidae	-	-	X	X
Spider A	X	X	X	X
Spider B	X	X	-	-
Spider C	X	-	X	X
Harvestmen	X	X	X	X
Archeboriolus	-	-	-	X
Bisolilius	X	X	X	X
Scytonotus	-	-	X	X
Velvet mite	-	-	X	-
Total	36	38	41	41

Table 5 Jaccard's Similarity indices of the cryptozoic community for unplowed-plowed and unplowed-unplowed comparisons in pasture and zerotill soil. Values closest to 1 indicate the greatest similarity between unplowed and plowed plots. Each value is an average of two plots.

Number of days after plowing	Pasture unplowed-unplowed	Pasture unplowed-plowed	Zerotill unplowed-unplowed	Zerotill unplowed-plowed
Pre-plowing	0.445	-	0.393	-
7	0.311	0.363	0.417	0.378
14	0.438	0.429	0.438	0.461
21	0.306	0.357	0.444	0.389
30	0.233	0.342	0.241	0.357
46	0.314	0.297	0.233	0.399
53	0.269	0.317	0.343	0.522
62	0.560	0.381	0.609	0.544
69	0.444	0.538	0.556	0.404
80	0.615	0.509	0.440	0.396
93	0.276	0.465	0.533	0.504
109	0.524	0.379	0.391	0.311
130	0.259	0.378	0.333	0.250
142	0.389	0.270	0.450	0.339
157	0.313	0.222	0.429	0.293
170	0.375	0.222	0.538	0.323

The abundances of slugs and sowbugs, the most common invertebrates found under cryptozoa boards are shown in Figures 7 and 8. The number of slugs in pasture and zerotill plots was similar initially, and was highest in plowed pasture and unplowed zerotill soil towards the end of the sampling period. A similar trend was observed with the number of sowbugs, except that the number of sowbugs was higher in pasture unplowed than in plowed soil in mid-summer.

The total number of animals found under cryptozoa boards was generally highest in unplowed pasture soil (Figure 9) although abundance in unplowed zerotill soil was close throughout the sampling season. In late fall, abundance was highest in unplowed and plowed zerotill soil.

Species richness under cryptozoa boards was highly variable, and there was no consistent difference between pasture and zerotill soil (Figure 10).

4. Number of mites

Mites were the most abundant animal extracted from the soil cores, followed by springtails, centipedes, millipedes and ants. The number of mites extracted from soil cores was higher in pasture soils than in zerotill soil (Table 6) over the entire sampling period. A similar trend was observed with the total number of animals extracted from soil cores (Table 7).

The occurence of mite, springtail and other invertebrate taxa was very similar in all four plot types.

Figure 7 Number of slugs found under cryptozoa boards in pasture and zerotill unplowed (□,▲) and plowed (○,▼) soils before and after plowing.

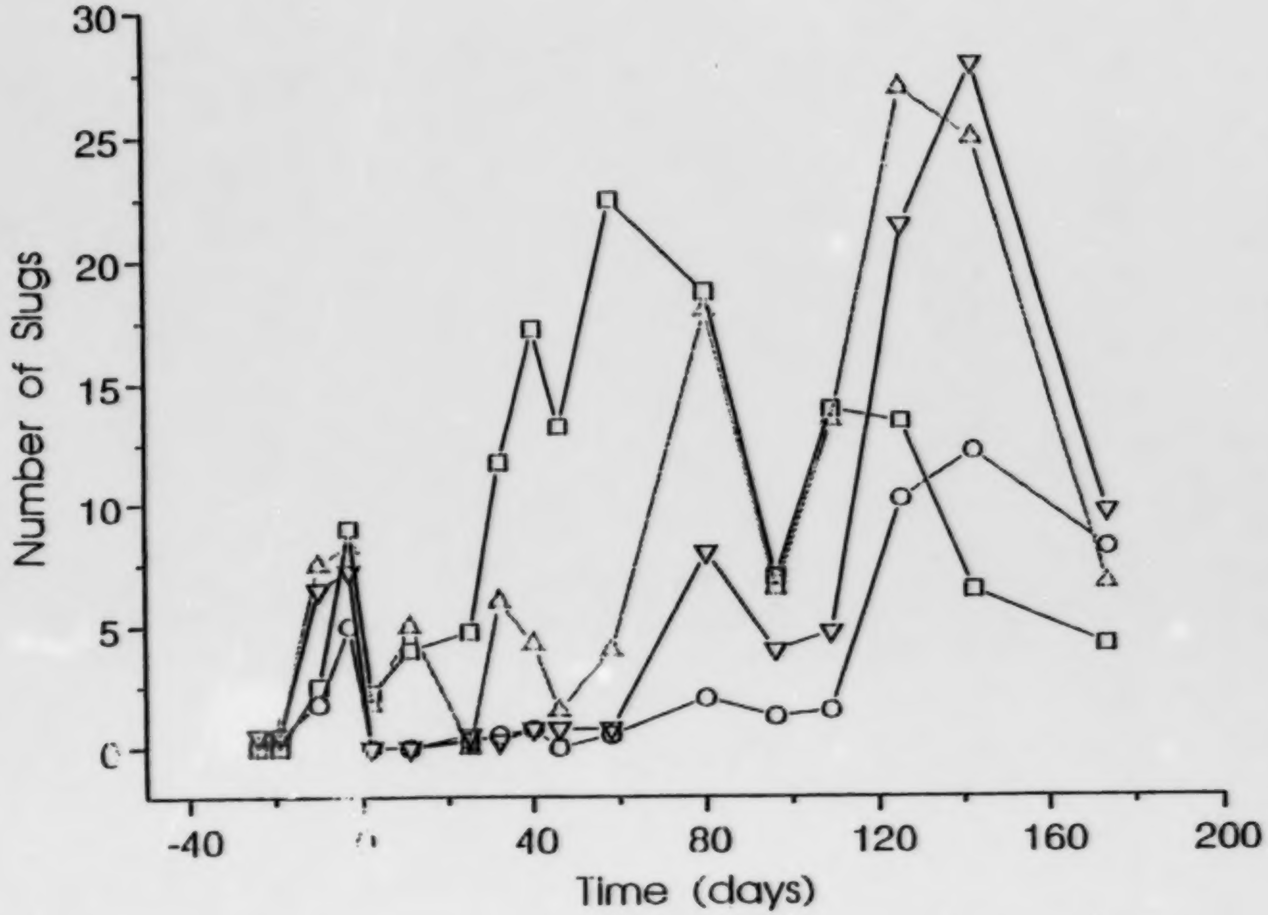


Figure 8 Number of sowbugs found under cryptozoa boards in pasture and zerotill unplowed (□,▲) and plowed (○,▼) soils before and after plowing.

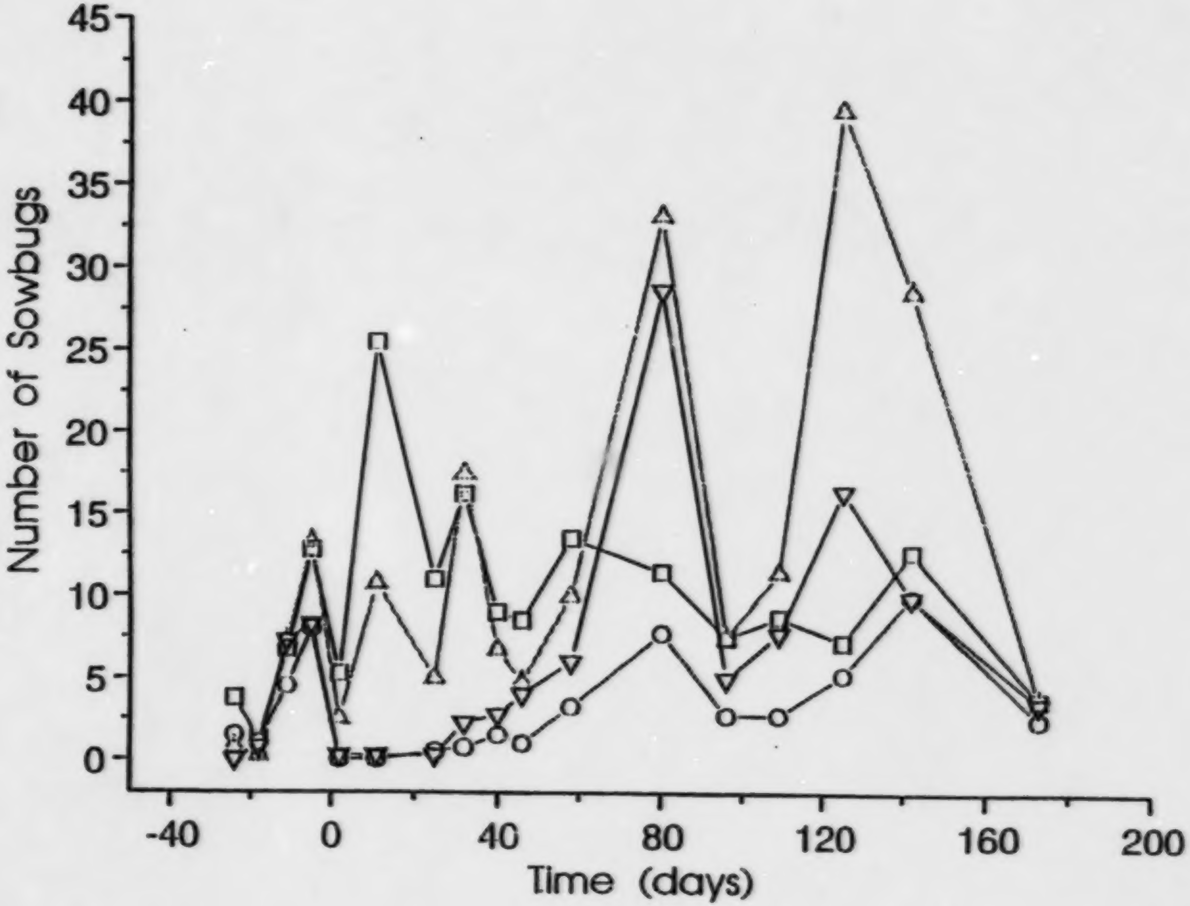


Figure 9 Total number of animals found under cryptozoa boards in pasture and zerotill unplowed (□,▵) and plowed (○,▿) soils before and after plowing.

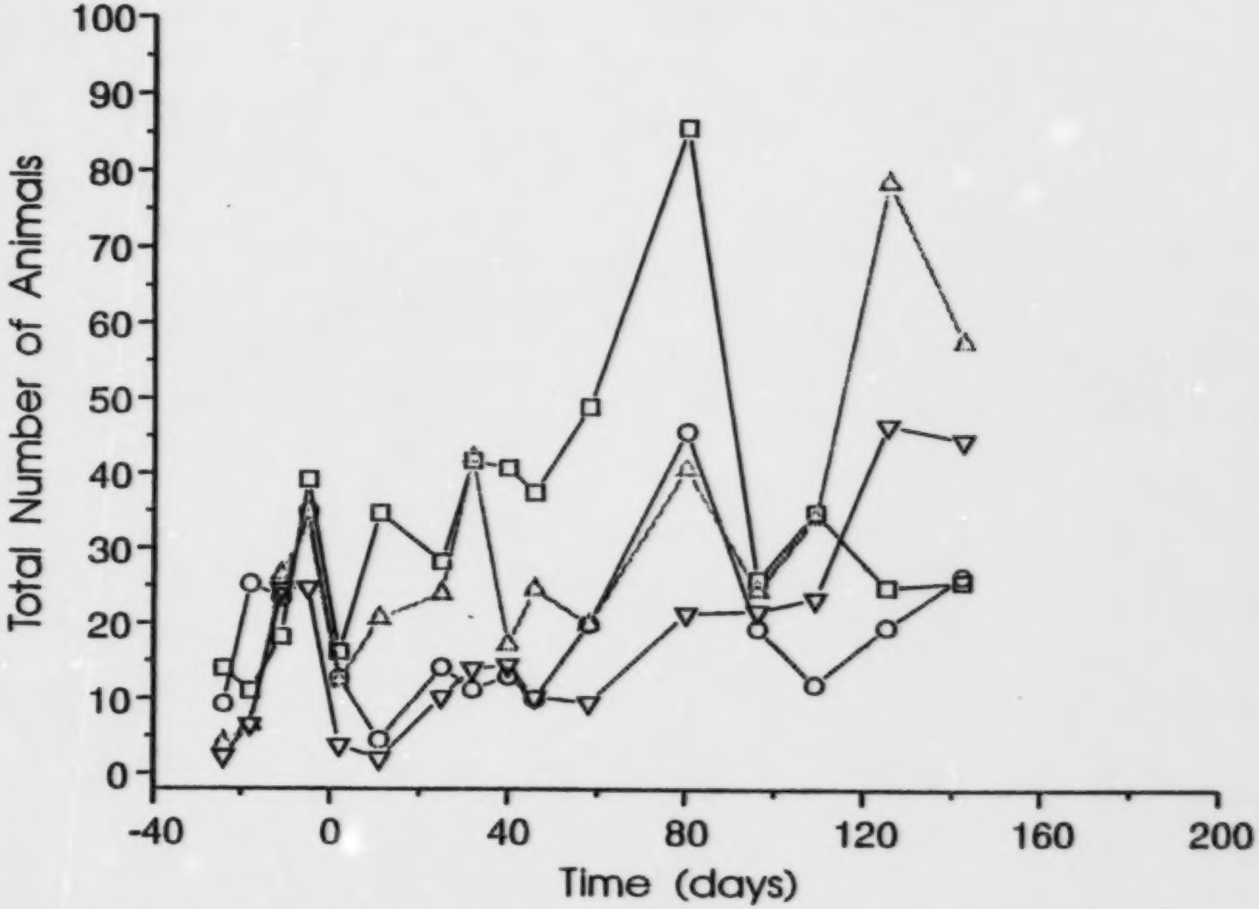


__Figure 10__ Number of taxa (richness) of animals found under cryptozoa boards in pasture and zerotill unplowed (□,▲) and plowed (o,▼) soils before and after plowing.

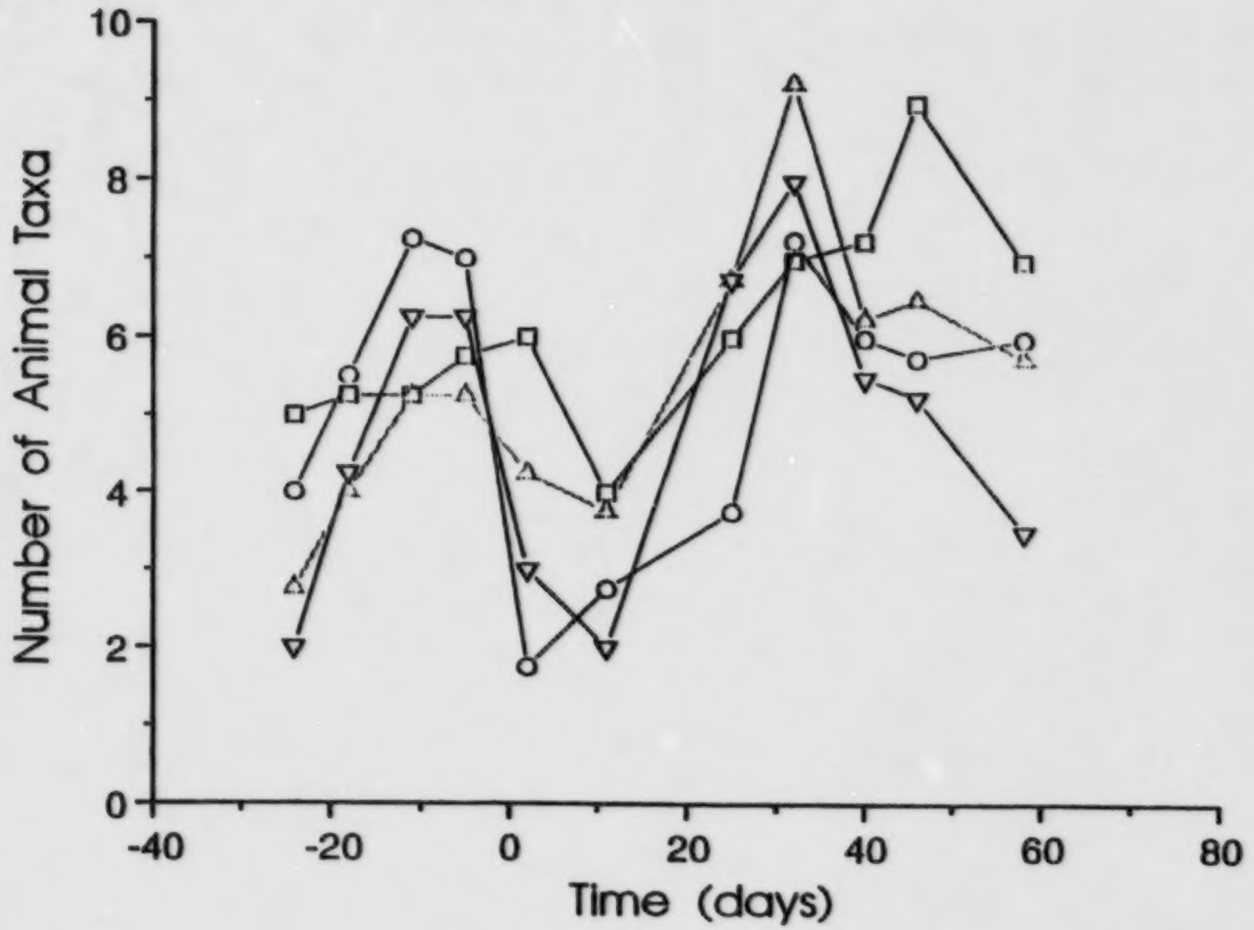


Table 6 The number of mites extracted from 0-15cm depth in unplowed and plowed pasture and zerotill soil. Number of mites is expressed as log(n+1) to remove the effect of aggregation. Each value is an average of eight samples.

Number of days after plowing	Number of mites			
	Pasture unplowed	Pasture plowed	Zerotill unplowed	Zerotill plowed
-24	1.86	1.70	1.51	1.48
-11	1.75	1.54	1.19	1.53
0	Day of plowing			
4	1.50	1.70	1.33	1.20
18	1.41	1.24	1.20	1.22
32	1.26	1.27	1.28	1.06
59	1.43	1.38	1.02	0.98
80	1.46	1.37	1.24	1.36
107	1.29	1.50	1.15	1.31
144	1.40	1.59	1.32	1.30

Table 7 The total number of animals extracted from 0-15cm depth in unplowed and plowed pasture and zerotill soil. Total number of animals is expressed as log(n+1) to remove the effect of aggregation. Each value is an average of eight samples.

Number of days after plowing	Total number of animals			
	Pasture unplowed	Pasture plowed	Zerotill unplowed	Zerotill plowed
-24	2.01	1.96	1.72	1.59
-11	2.14	1.93	1.70	1.92
0	Day of plowing			
4	1.88	1.95	1.68	1.38
18	1.80	1.56	1.61	1.61
32	1.97	1.81	1.59	1.35
59	1.75	1.85	1.49	1.34
80	1.88	1.96	1.61	1.62
107	1.81	1.70	1.43	1.57
144	1.66	1.91	1.61	1.62

5 i) Soil biomass Carbon and Nitrogen

Soil biomass values at 0-20 cm depth oscillated throughout the season (Figure 11). Biomass values appear to be relatively constant over the season with a small peak in June and a decline in late July and August. Soil biomass was almost always higher in the pasture soil. On average over the entire season pasture biomass was 100 ug C/g soil higher than biomass in zerotill soil.

Soil biomass in plowed and unplowed plots generally mirrored each other for the entire sampling period. However, soil biomass values in the plowed soil fluctuated above and below unplowed soil biomass values. Soil biomass nitrogen mirrored that of biomass carbon in both pasture and zerotill soils.

ii) Soil biomass P

Soil biomass P measurements were extremely variable and often resulted in negative soil biomass. Only one sample date, Sept. 28 provided consistent results (Table 8).

Soil biomass P was very similar over 0-20 cm in pasture and zerotill soil, however this value is distributed differently with depth. In zerotill soil, biomass P is much higher at 0-10 cm depth than at 10-20 cm depth where in pasture soil biomass values are similar at both depths (Table 8).

Soil biomass C:P ratios were generally higher in pasture soil than in zerotill, 11.0 and 7.0 respectively for 0-20 cm.

6. Emergent invertebrates

The seasonal trend of abundance and richness of the emergent invertebrates was

Figure 11 Soil microbial biomass found in 0-20 cm of soil in pasture and zerotill soils before and after plowing.

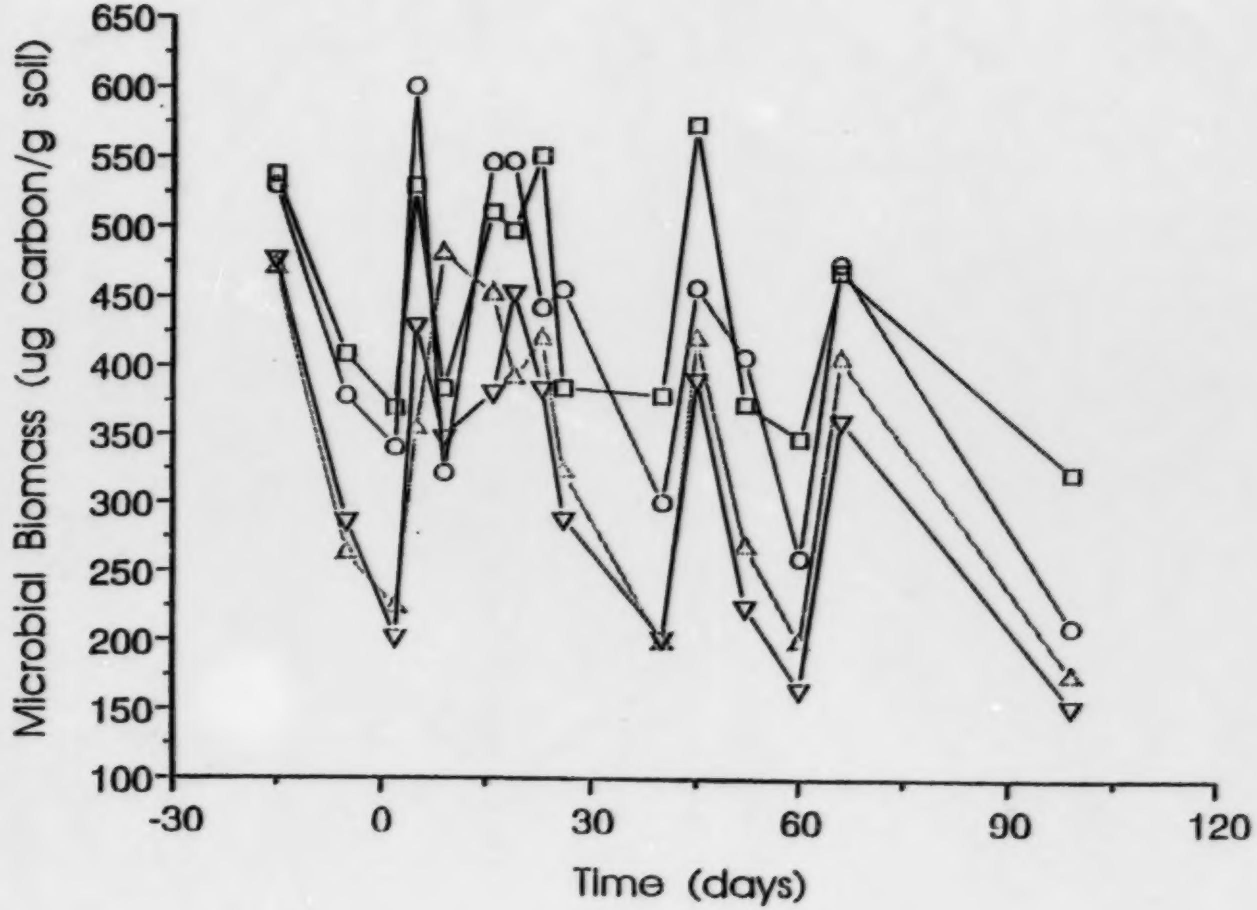


Table 8 Soil biomass P values obtained on September 28. Values are averages of measurements in unplowed plots.

Cropping system	Depth	Biomass P (ug/g soil)	C:P ratio
Pasture	0-10 cm	30.1	14.0
	10-20	28.8	8.0
	0-20	58.9	11.0
Zerotill	0-10	40.9	5.8
	10-20	19.3	9.4
	0-20	60.2	7.0

a general increase throughout the summer. Plowed populations mirrored the unplowed population in both cropping systems (Figures 12 and 13).

Abundance of animals captured in emergence traps was highest in pasture unplowed and plowed soils (Figure 12). At the peak of emergence, the emergence traps were capturing approximately 180 individuals/m^2 in pasture unplowed soil and 110 individuals/m^2 in zerotill unplowed soil.

Species richness was also higher in pasture unplowed and plowed soils than in zerotill soils (Figure 13).

Eveness of the emergent animal populations was highly variable in pasture and zerotill soils (Figure 14), but was higher at several sampling times in zerotill soil.

Occurrence of emergent invertebrates in the four plot types is shown in Table 9. Occurence was slightly higher in pasture soils. The most dominant invertebrates captured in the emergent traps including Anthomyiidae, Sciaridae, Syrphidae, Braconidae and others were found in all four plot types. Differences in occurrence are due to the presence or abscence of rarer species.

After plowing, similarity in pasture soil was greatest in unplowed-unplowed comparisons, and it was not until 39 days after plowing that similarity in unplowed-plowed comparisons was comparable. Similarity in zerotill soils was close in unplowed-unplowed and unplowed-plowed comparisons immediately after plowing.

7. Litter Decomposition Rate

Litter decomposition rate (change in dry weight per day) was measured using

Figure 12 Abundance of emergent invertebrates in pasture and zerotill unplowed (□,△) and plowed (○,▽) soils before or after plowing.

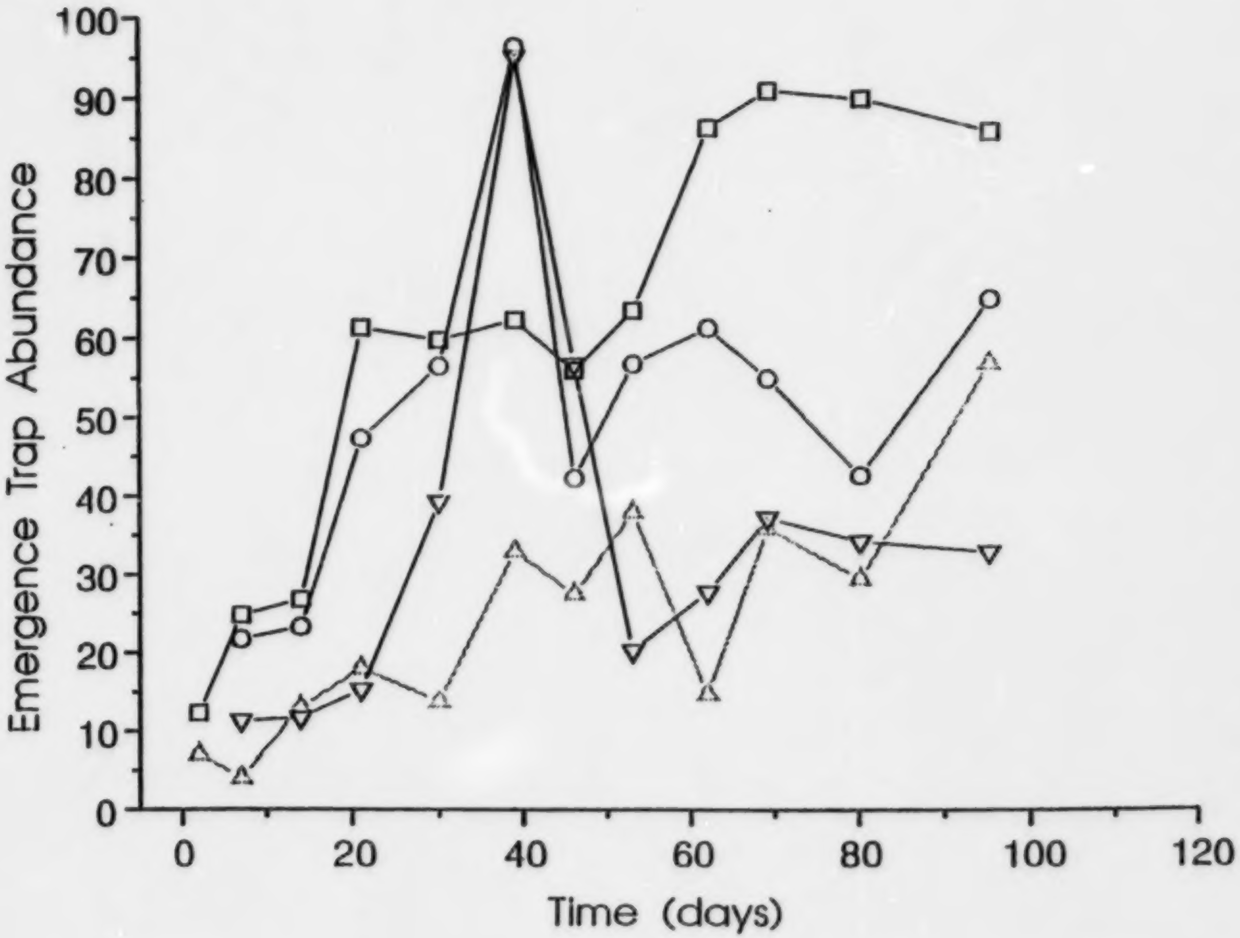


__Figure 13__ **Number of taxa captured in emergence traps in pasture and zerotill unplowed (□,▵) and plowed (○,▿) soils before and after plowing.**

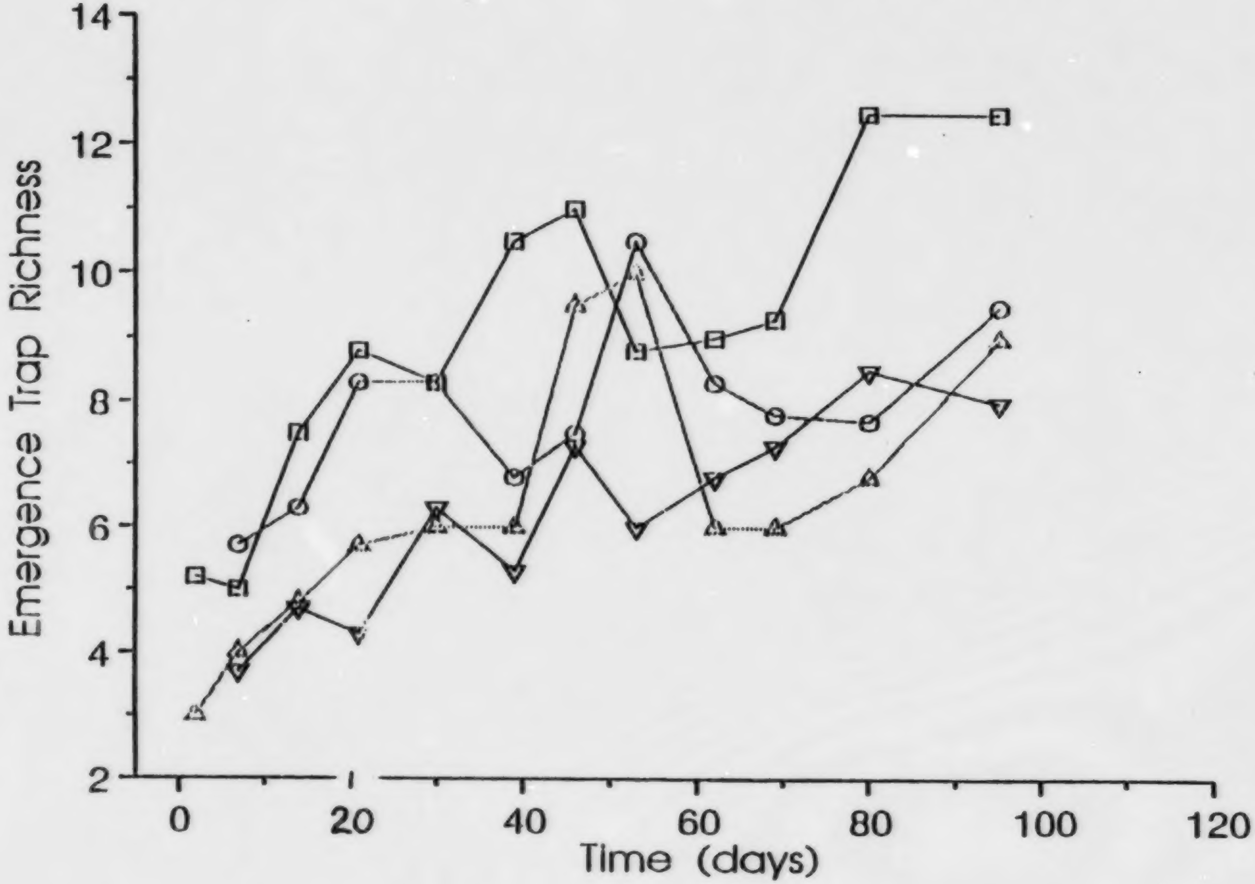


Figure 14 Eveness of the emergent community in pasture and zerotill unplowed (□,△) and plowed (○,▽) soils before and after plowing.

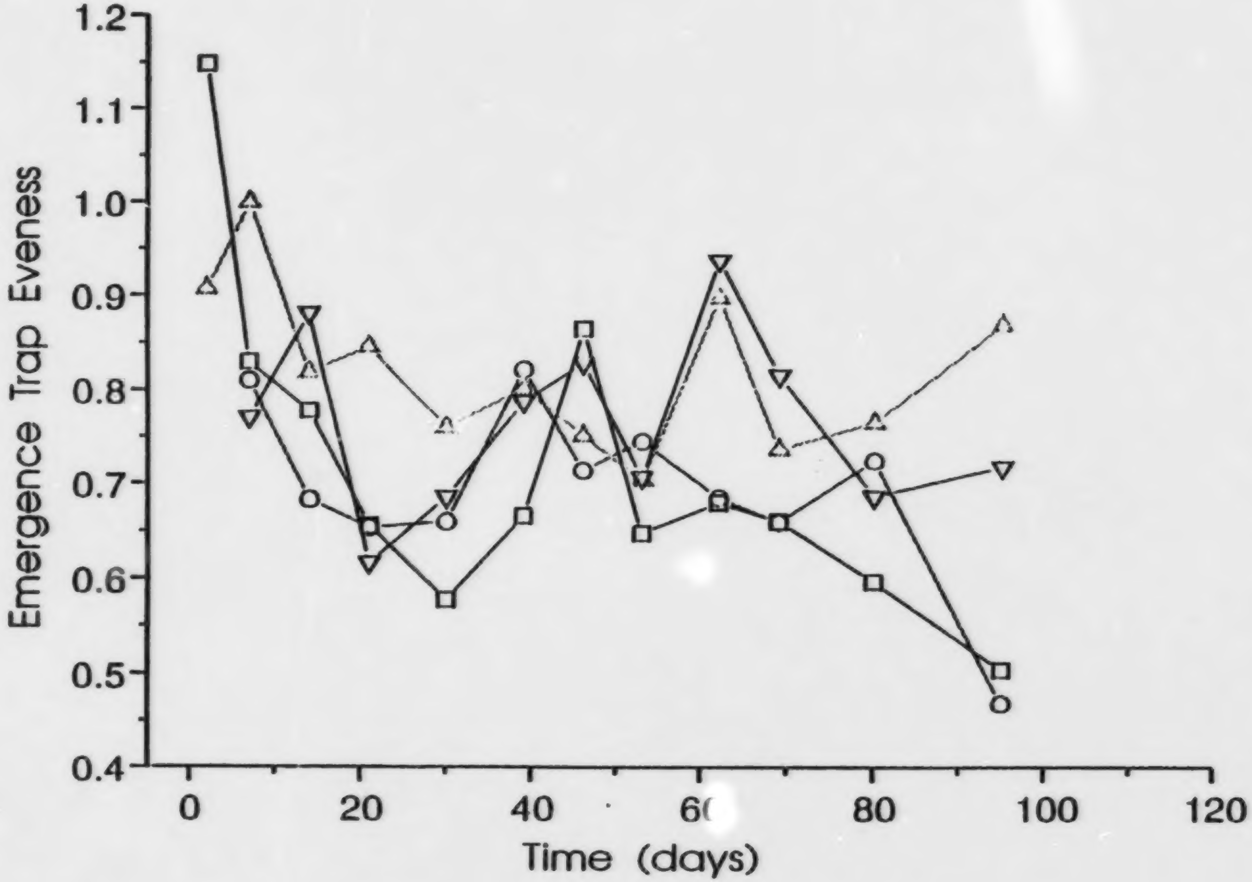


Table 9 Occurrence (X) and absence (-) of emergent animals in pasture and zerotill unplowed and plowed soil. A list of common and scientific names is provided in Appendix I.

Species / taxa	Pasture unplowed	Pasture plowed	Zerotill unplowed	Zerotill plowed
slugs	X	X	X	X
Entomobryinae	-	X	X	-
Sminthurinae	-	-	X	-
Acrididae	X	X	X	X
Gryllinae	X	X	-	-
Earwigs	X	X	X	X
Leafhopper	X	X	X	X
Planthopper	X	-	X	-
Nabidae	X	X	X	X
Brown lacewing	-	X	-	-
Walking stick	-	-	-	X
aphid	X	X	-	X
Silphidae	-	-	X	-
Carabidae	X	-	X	-
Nitidulidae	X	X	X	X
Staphylinidae	X	X	X	X
Cantharidae	X	-	X	X
Coccinellidae	X	X	X	X
Scarabaiedae A	X	-	-	-
Scarabaiedae B	X	-	-	-
Curculionidae	X	X	X	X
Noctuidae	X	X	X	X
Diptera A	X	X	X	X
Diptera B	X	X	X	X
Diptera C	X	X	X	X
Diptera D	X	X	-	X
Sciaridae	X	X	X	X
Mycetophilidae	X	X	X	-
Phoridae	X	X	X	X
Syrphidae	X	X	X	X
Empididae	X	X	X	X
Calliphoridae	X	X	X	X
Anthomyiidae	X	X	X	X
Drosophilidae	X	-	-	X
Pipinculidae	X	X	-	-
Braconidae	X	X	X	X
Formicidae	X	X	X	-
Apidae	-	-	X	-
Spider	X	X	X	-
Harvestmen	X	X	X	-
Nothrus	-	-	-	X
Total =	34	30	31	26

litterbags placed on the surface and buried at 10 cm.

With the exception of unplowed pasture soil at 10 cm depth, litter decomposition rate was higher in the zerotill soil than in pasture soil 39 and 69 days after plowing. 103 and 138 days after plowing decomposition rates overlapped each other in pasture and zerotill soil (Table 10).

39 days after plowing litter decomposition rate was highest at 10 cm depth in unplowed soil in the pasture cropping system, but was highest in the plowed surface soil in the zerotill system (Table 10).

8. Saturated hydraulic conductivity of soils

Saturated hydraulic conductivities (Kfs) in unplowed and plowed zerotill soils are not significantly different(t-tests, $p > 0.05$; Table 11). However, in pasture soils saturated hydraulic conductivity was greater by a factor of ten in the plowed soil ($t=7.76$, $df=14$, $p < 0.001$). Kfs and the number of nematodes present in pasture soil were correlated in seven of the eight plots (Spearman's rank correlation, $p < 0.05$). Kfs and the number of mites, total number of organisms (from cores), and the number and mass of earthworms were not correlated (Spearman's rank correlation, $p > 0.05$). None of these populations was correlated with Kfs in the zerotill soil.

Dry bulk density (DBD) of the soils at the same time as the hydraulic conductivities were taken are shown in Table 12. DBD was similar in unplowed and plowed pasture soils. DBD was highest in zerotill unplowed soils, significantly higher

Table 10 Change in dry weight per day of litterbags at the surface and at 10cm depth in unplowed and plowed pasture and zerotill soil. Each value is an average of four determinations and its standard error is in brackets.

Date and # of days after plowing	Change in dry weight (g/day)							
	Pasture unplowed		Pasture plowed		Zerotill unplowed		Zerotill plowed	
	Surf.	10cm	Surf.	10cm	Surf.	10cm	Surf.	10cm
July 4 (+39)	.069 (.024)	.197 (.024)	.125 (.010)	.104 (.014)	.135 (.042)	.119 (.025)	.208 (.126)	.171 (.025)
August 3 (+69)	.105 (.030)	.089 (.084)	.099 (.013)	.101 (.022)	.127 (.013)	.137 (.015)	.120 (.008)	.152 (.018)
Sept 6 (+103)	.073 (.013)	.087 (.015)	.066 (.010)	.129 (.039)	.057 (.013)	.084 (.004)	.084 (.076)	.094 (.018)
Oct 17 (+138)	.073 (.015)	.051 (.024)	.068 (.011)	.042 (.005)	.060 (.027)	.065 (.004)	.077 (.011)	.051 (.007)

Table 11 Saturated hydraulic conductivity in unplowed and plowed pasture and zerotill soils. Values given are means of eight determinations, and standard errors are in brackets. Units are cm/s.

	Pasture	Zerotill
Unplowed	2.58×10^{-4}	1.93×10^{-3}
	(2.29×10^{-3})	(9.18×10^{-4})
Plowed	2.27×10^{-3}	1.50×10^{-3}
	(1.24×10^{-3})	(6.61×10^{-4})

Table 12 Dry bulk densities (g/cm^3) and their standard error in the four plot types.

	Pasture	Zerotill
Unplowed	1.11 (0.10)	1.24 (0.06)
Plowed	1.11 (0.07)	1.11 (0.05)

than in zerotill plowed soil (t=3.35, df=46, p<0.005).

9. Water Infiltration rate

The average infiltration rate increased with increasing earthworm number and earthworm mass. Average infiltration rate is significantly correlated with earthworm number but not earthworm mass (Spearman's rank correlation, p <0.05).

The infiltration rate was on average higher in unplowed pasture and zerotill soils than in the plowed soil (Table 13). The difference between unplowed and plowed soil infiltration rate in zerotill soil was significant(t=3.22, df=14, p <0.01).

10. Plant Dominance

Winter wheat was the dominant plant in unplowed zerotill soil. Average dominance in all unplowed plots was 70%. Pigweed (Amaranthus retroflexus) was the dominant plant in plowed zerotill soil. Average dominance of pigweed in all plots was 78%.

Grass (Agropyron repens) was the dominant plant in both plowed and unplowed pasture soils. Grass dominance was 44% in unplowed plots, and dominance in plowed plots was 50%.

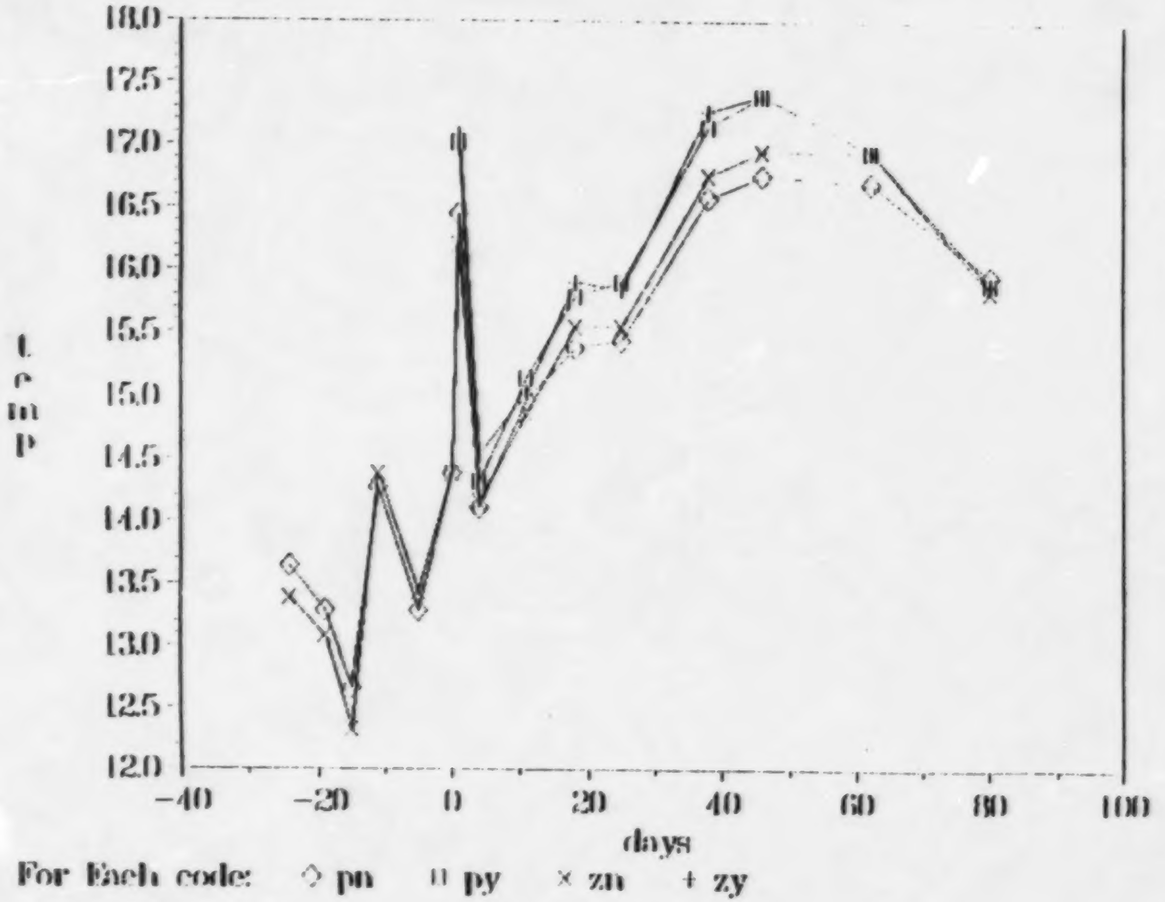
11. Soil temperature

Variation in soil temperature over 2.5 to 17.5 cm depth in pasture and zerotill soils is shown in Figure 15. Soil temperatures in pasture and zerotill soils are similar in both

Table 13 Average infiltration rate for unplowed and plowed pasture and zerotill soils. Values given are the means of eight determinations. Average infiltration rate is averaged over four plots.

	Infiltration rate $cm/s/cm^2$	
	Pasture	Zerotill
Unplowed	7.43×10^{-4}	8.18×10^{-4}
	(3.15×10^{-5})	(1.17×10^{-4})
Plowed	6.61×10^{-4}	5.30×10^{-4}
	(1.06×10^{-4})	(6.16×10^{-5})

Figure 15 Soil temperature in pasture and zerotill unplowed (◊,X) and plowed (□,+) soils before and after plowing. Soil temperature is averaged over 2.5-17.5 cm depth.

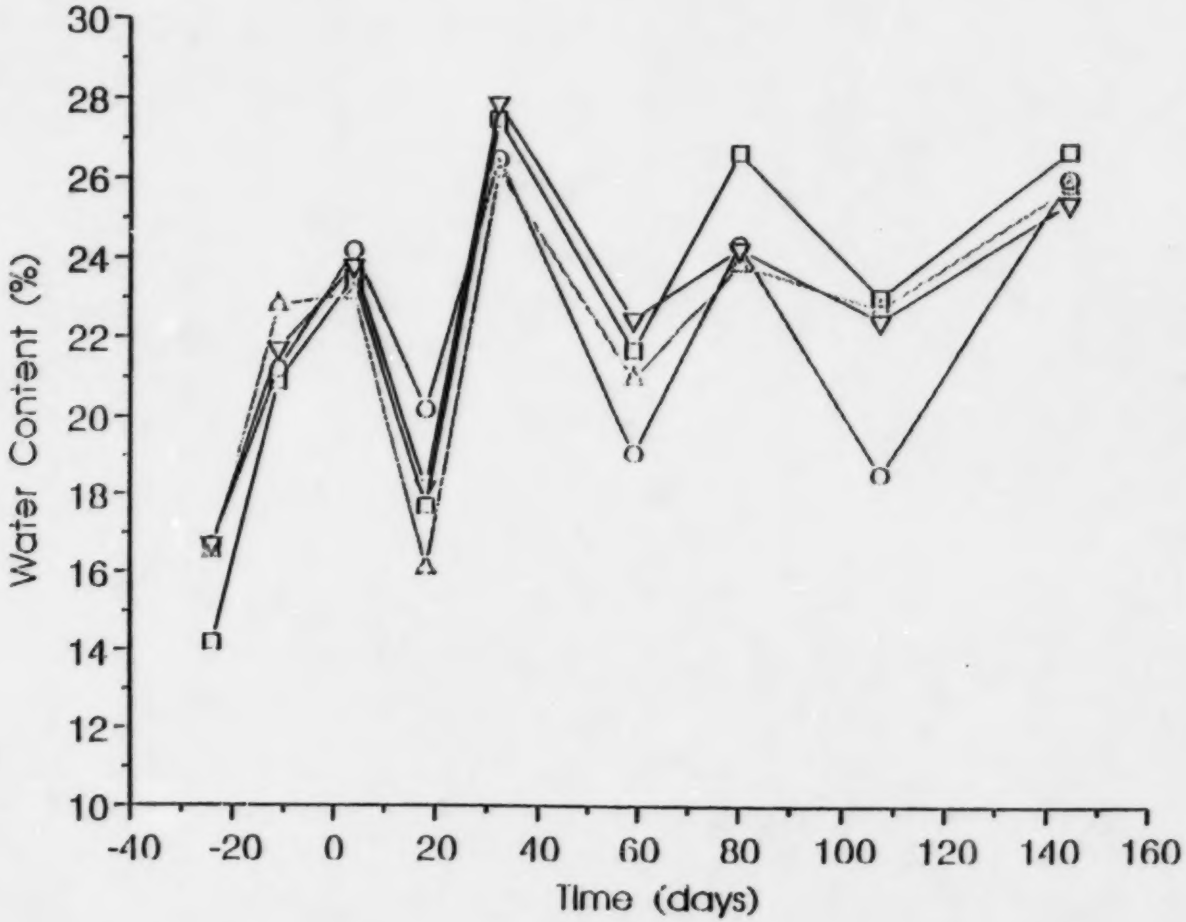


unplowed and plowed soils. Zerotill and pasture plowed soils initially had a higher temperature than unplowed soils but this difference had disappeared by late summer.

12. Water content

Water contents of unplowed and plowed pasture soils were usually similar, no consistent differences appearing over the sampling period (Figure 16).

__Figure 16__ Water content in pasture and zerotill unplowed (□,▲) and plowed (○,▼) soils before and after plowing. Water content is averaged over 0-15 cm depth.



As the numbers of mites and other animals extracted from soil cores were so variable, multiple regression models were run for six mite sampling dates to determine which biotic and abiotic factors reduced the variability of the number of mites, the number of species of mites, and the total number of animals extracted per core.

Table 14 gives the results of these multiple regression models in which the independent variable is the number of mites. Dependent variables considered included cropping system (pasture or zerotill), tillage (yes or no), depth, number of springtails, number of other organisms, water content, wet bulk density and organic matter content of the soil. Cropping system, depth, number of springtails, number of other organisms and organic matter content helped to explain the variation (ie their model parameter estimate was significant) in the number of mites in at least three of the sampling times. Tillage, water content and wet bulk density do not appear to be as important in explaining the variation in the number of mites found in a sample. These dependent variables had influence in only one of the six sampling times.

Table 15 gives the results of multiple regression models run with the number of species of mites extracted from a core as the independent variable. Cropping system, depth and organic matter content of the soil appeared to be the most important variables that help explain the variation in number of species of mites extracted from a core. These dependent variables were significant in three of the six sampling times. Number of springtails and number of other animals helped to explain variation in the number

Table 14 Factors that helped to explain the variation in the number of mites in a multiple regression model. Y indicates that the factor helped to explain variation, and N indicates that no variation was explained by the variable. A positive or negative sign next to Y or N indicates whether the factor in question positively or negatively influenced the number of mites.

Sample date	Factor							
	Cropping system	Tillage	Depth	Number of Spring-tails	Number of Other animals	Water cont.	Wet bulk dens.	SOM
May 2	Y-	-	Y-	N	Y-	N	N	N
May 15	Y-	-	N	Y+	Y-	N	N	Y+
May 26	Day of plowing							
May 30	N	N	N	Y+	N	N	N	Y+
August 14	N	N	N	Y+	N	N	N	Y+
Sept. 10	N	N	Y+	N	Y+	Y+	Y-	Y+
Oct. 17	Y-	Y+	Y+	N	N	N	N	
Number of samples factor helped explain variation in	3-	1+	2+ 1-	3+	1+ 2-	1+	1-	4+

Table 15 Factors that helped to explain the variation in the number of mite species in a multiple regression model. Y indicates that the factor helped to explain variation, and N indicates that no variation was explained by the variable. A positive or negative sign next to Y or N indicates whether the factor in question positively or negatively influenced the number of mite species.

Sample date	Factor							
	Cropping system	Tillage	Depth	Number of spring-tails	Number of others animals	Water cont.	Wet bulk dens.	SOM
May 2	Y-	-	Y-	N	N	N	N	N
May 15	N	-	N	N	Y+	N	N	Y+
May 26	Day of plowing							
May 30	Y-	N	N	N	N	N	N	Y+
August 14	N	N	Y-	Y+	N	N	N	N
Sept 10	N	Y+	Y+	N	Y+	Y+	N	Y+
Oct 17	Y-	N	N	N	Y+	N	Y-	N
Number of samples factor helped explain variation in	3-	1+	1+ 2-	1+	3+	1+	1-	3+

of species extracted in two sampling times and tillage, water content and bulk density helped to explain variation in one sampling time.

Table 16 gives the results of multiple regression models run with the total number of animals extracted as the independent variable. Cropping system helped to explain variation in the total number of organisms in five of six sampling times. Organic matter content and wet bulk density were less important, explaining variation in three and two sampling times respectively. Tillage and depth helped explain variation at one sampling time, and water content explained no variation.

The average number of mites per core at different depths is shown in Table 17. The general trend in pasture and zerotill unplowed soil is that mite number is greatest at the soil surface (0-5 cm) and decreases with depth. This trend is not observed in the plowed soil immediately after plowing. In the pasture, plowed soil had the highest number of mites per core at 5-10 and 10-15 cm and almost no mites at the surface on May 30, June 13 and June 27. Plowed zerotill soil showed a similar trend on these sample dates, most mites were found below the surface layer from 5-15 cm. By July 24 this trend had partially reversed itself and the mites had begun to return to the top 5 cm of plowed pasture and zerotill soil (Table 17).

A very similar trend was observed for average total number of animals extracted per core (Table 18). In unplowed pasture and zerotill soil the greatest number of animals was found in the surface soil (0-5 cm). In plowed pasture and zerotill soil the majority of animals were initially found at greater depths (5-15 cm). In plowed soil, number of animals increased in the surface soil on July 24 but did not remain high at

Table 16 Factors that helped to explain the variation in the total number of animals extracted in a multiple regression model. Y indicates that the factor helped to explain variation, and N indicates that no variation was explained by the variable. A positive or negative sign next to Y or N indicates whether the factor in question positively or negatively influenced the total number of animals extracted.

Sample date	Factor					
	Cropping system	Tillage	Depth	Water cont.	Wet bulk dens.	SOM
May 2	Y-	-	Y-	N	N	N
May 15	N	-	N	N	N	Y+
May 26	Day of plowing					
May 30	Y-	N	N	N	N	Y+
August 14	Y-	N	N	N	Y-	N
Sept 10	Y-	N	N	N	N	Y+
Oct 17	Y-	Y+	N	N	Y-	N
Number of samples factor helped explain variation in	5-	1+	1-	0	2-	3+

Table 17 Average number of mites per core at different depths.

Sample	Depth	Cropping system			
		Pasture unplowed	Pasture plowed	Zerotill unplowed	Zerotill plowed
May 2	0-5	5.6	-	3.6	-
	5-10	6.3	-	2.6	-
	10-15	3.3	-	1.4	-
May 15	0-5	4.4	-	2.4	-
	5-10	3.9	-	2.0	-
	10-15	2.9	-	1.5	-
May 30	0-5	3.5	0.7	1.6	0.5
	5-10	2.0	2.8	3.3	1.1
	10-15	2.1	7.7	0.5	2.1
June 13	0-5	3.5	0.3	1.4	0.3
	5-10	1.5	1.8	1.3	2.1
	10-15	1.3	2.1	1.1	1.5
June 27	0-5	1.5	0.5	2.0	0.6
	5-10	1.3	2.9	0.5	1.0
	10-15	1.5	0.8	1.6	0.2
July 24	0-5	4.9	1.9	1.3	1.0
	5-10	1.4	1.4	0.4	0.9
	10-15	0.9	2.1	0.8	0.4
August 14	0-5	3.0	2.4	2.0	1.8
	5-10	1.8	1.1	1.6	2.6
	10-15	1.9	2.0	1.2	1.1
Sept. 10	0-5	2.8	1.5	1.3	1.4
	5-10	1.3	3.5	1.1	1.8
	10-15	0.6	3.1	0.8	1.8
October 17	0-5	2.1	4.2	3.4	1.0
	5-10	2.6	4.0	0.6	1.8
	10-15	1.3	2.4	1.0	2.0

Table 18 Average abundance of animals per core at different depths.

Sample	Depth	Cropping system			
		Pasture unplowed	Pasture plowed	Zerotill unplowed	Zerotill plowed
May 2	0-5	9.3	-	4.4	-
	5-10	9.0	-	4.1	-
	10-15	5.7	-	2.3	-
May 15	0-5	11.2	-	6.9	-
	5-10	7.4	-	5.6	-
	10-15	7.7	-	4.7	-
May 30	0-5	8.5	2.4	4.4	1.0
	5-10	7.5	4.7	4.6	1.9
	10-15	2.9	12.6	2.1	2.9
June 13	0-5	7.4	1.3	4.8	0.5
	5-10	4.8	4.0	2.9	7.1
	10-15	3.4	3.6	2.3	2.5
June 27	0-5	7.4	1.3	4.8	0.5
	5-10	10.0	11.1	1.7	2.3
	10-15	5.6	2.3	2.4	1.0
July 24	0-5	8.7	5.5	4.4	1.5
	5-10	2.3	5.3	1.6	1.8
	10-15	3.8	6.1	1.3	2.1
August 14	0-5	8.9	5.4	5.3	2.6
	5-10	4.3	13.3	3.6	5.1
	10-15	5.3	4.9	1.2	2.5
Sept 10	0-5	6.9	2.8	2.9	3.1
	5-10	6.4	5.9	1.6	2.8
	10-15	2.8	4.1	2.0	3.3
October 17	0-5	5.5	9.2	5.6	2.9
	5-10	3.5	7.1	2.6	3.6
	10-15	2.3	6.0	1.8	3.8

this depth consistently for the rest of the sampling period.

Chapter 6 Soil Mixing by Plowing and Disking

The amount of soil mixing accomplished by moldboard plowing and disking is shown in Table 19. Prior to plowing in soil with no KCl added, the chloride ion count was 16.6-18.7 ppm. This value represents the background value that is naturally found in the soil. All soil without KCl added should have an amount of chloride ion present similar to this value.

In plots with KCl added to the surface before plowing, the surface soil (0-5 cm) has the highest chloride content. The soil core increments below this surface core should have only background chloride values. However these values are much higher than the background values, probably because some chloride was pushed from the surface to these depths by the coring tool. Therefore, except where cores were taken, chloride values from 5-20 cm depth were at background levels.

After plowing, the "in line" chloride values were highest at 10-15 cm (47.5 ppm) followed by 15-20 cm depth (32.7 ppm), and lowest from 0-5 and 5-10 cm. These values indicate that the sod has been partially inverted as the highest chloride values have moved from the surface to nearer the plowing depth.

In the "out of line" plots there was a buildup of chloride ion at 5-10 cm and all other depths remained at background levels. This pattern is probably again due to the partial inversion of the sod layer, with the surface of the sod now being found most commonly from 5-10 cm.

Disking the "in line" plots helped to mix the chloride (and soil) more uniformly. Disking increased the chloride ion content substantially in the surface soil and less was

Table 19 Chloride ion content (ppm) of plots with (or in line with) KCl added and without (or out of line with) KCl added to the soil.

Time	Depth	KCl added	No KCl added
Before plowing	0-5	345.7	18.7
	5-10	71.4	17.2
	10-15	46.9	16.6
	15-20	20.4	17.2
After plowing	0-5	12.9	12.4
	5-10	11.4	98.6
	10-15	47.5	16.6
	15-20	32.7	18.0
After disking	0-5	77.4	14.8
	5-10	15.8	82.0
	10-15	46.9	44.1
	15-20	15.6	14.0

found from 15-20 cm. This pattern can be attributed to the action of the disks, they cut up the sodlayer, and their angle helps to redistribute the soil by throwing it to one side. Disking in the "out of line" plots also helped to redistribute the chloride ions (and the soil) as there was a substantial increase in chloride ion at 10-15 cm.

These results indicate that the action of the moldboard plow and tandem disks is not just to invert and loosen the soil. Clearly there is some mixing through all depths.

Chapter 7 General Discussion

1. Nematodes

Return time was relatively short for the number of nematodes. Rapid recovery from the plowing and disking disturbance is probably not due to rapid reproduction, studies on several species show that the main reproductive period is in March, April and May, and that there is probably only a single generation per year. Rapid recovery may be due to survival of eggs and cysts (Yeates, 1979).

The seasonal trend observed in pasture and zerotill soil is similar to that of other studies. Sohlenius (1979) observed a similar peak in September and a decrease from early April to early June.

Sohlenius (1989) studied nematodes on a perrenial grass ley and also found that they recovered quickly after plowing. This study showed that the nematode populations decreased in plowed soil, but Sohlenius found that the populations increased. Nematode population size in the grass ley soil were about half that reported in this study. Differences in abundance and effect of plowing are probably due to cropping system and climactic differences.

Soil structure and the amount of inhabitable pore space are important soil properties that effect nematodes. Pore size and continuity is an important determinant of their mobility and therefore activity (Jones and Thomasson, 1976). Saturated hydraulic conductivity is an indirect measure of pore continuity as it measures the rate of saturated water flow through the soil. Number of nematodes was correlated with

saturated hydraulic conductivity in the pasture soil indicating that in this soil, pore size might be limiting activity. Nematodes can be seperated from their food source as bacteria often enter soil pores inaccessible to nematodes (Elliot et al, 1980).

2. Earthworms

The reproductive rate of earthworms is low compared to that of many soil animals. The number of cocoons produced per month under optimum conditions ranged from 0.3 to 12.0 with usually only one young worm per cocoon (Barley, 1963). This low reproductive rate helps to explain why the earthworm population did not return in pasture or zerotill soil. Cultivation generally decreases earthworm populations. This is attributed to mechanical damage during cultivation, decrease in availability of suitable food, destruction of permanent burrows, and increasing fluctuation in temperature and moisture changes (Edwards, 1983). Once the earthworm population was reduced by cultivation, its low reproductive rate could not bring it back to undisturbed levels in the sampling period. This was especially true in the pasture soil where it might take several years for the population to return. The earthworm population appears to be one group of animals that could not recover from cultivation in one sampling season.

The number of earthworms found in unplowed and plowed pasture and zerotill soil was correlated with water infiltration rate. This correlation is due to the large continous burrows earthworms create. Cultivated soil has twice as many macropores (pores >200 um diameter) as uncultivated soil, but uncultivated soil has 2 to 9 times

more bioporosity, mainly attributed to earthworms (Shipatalo and Protz, 1987). These biopores transmit water to depths of 180 cm taking off up to 1 liter per minute (Ehlers, 1975). It would appear that at this site the biopores transmit more water than the macropores created by plowing, because water infiltration rate was higher in unplowed soil for both pasture and zerotill soil (Table 13).

3. Cryptozoic fauna

Resilience of an ecosystem has been defined as " the persistence of systems and their ability to absorb change and disturbance and still maintain the same relationships between population or state variables" (Holling, 1973). Similarity was used in this study as an indirect measure of resilience. It is measuring whether the species were the same in the disturbed and undisturbed communities. Similarity between undisturbed communities and similarity between undisturbed-disturbed communities were close in both zerotill and pasture soil (Table 11). This agreement in values indicates there was no more difference in species composition in disturbed plots than there was in undisturbed plots. This indicates that the community of cryptozoic invertebrates is resilient in that the relationship between the types of species found in a plot does not appear to have changed.

4. Mites and springtails

The results of the multiple regression models help to explain why mite numbers were so variable. Initially the number of mites was partitioned into cropping system (pasture or zerotillage) and tillage (yes or no) for the basis of comparison. Examination

of Table 14 reveals however that tillage was not an important variable explaining variation in the number of mites. This result indicates that tillage alone, probably did not directly influence the distribution of mites. Changes in the soil after tillage appears to have had a greater influence. Partitioning samples using this variable therefore does not simplify the results.

Cropping system, depth, number of springtails, number of other organisms and organic matter content appear to be the driving variables determining mite distribution. With each of these dependent variables (except cropping system) varying considerably within a cropping system or tillage type, it is understandable why mite numbers in these treatments vary so greatly. If it was of interest to increase the number of mites or the number of species of mites in a soil, these models indicate which factors would likely have to be changed.

The average number of mites and total number of animals extracted per core decreased in the surface soil (0-5 cm) after plowing because of changes in soil temperature, water content and residue location. Mites and springtails prefer cooler soil temperatures, 10-12°C being their optimum (Christiansen, 1964). After plowing, soil temperature in plowed soil rose above that of unplowed soil (Figure 15) especially at the now exposed dark surface. In addition water content decreased in plowed soil (Figure 16), again particularly at the soil surface. This increase in soil temperature and water content was probably partially responsible for the movement of mites deeper into the soil. When soil temperatures became similar again in unplowed and plowed soil (late July/early August; Figure 15) animal numbers again increased in the surface soil.

Crop residues were relocated during plowing and disking. Residues that were formerly mainly on the soil surface were spread throughout the top 17 to 18 cm (Table 19; Chapter 6). The mites and springtails would prefer to stay with this now more rapidly decomposing residue and its accompyaning microflora and fauna once they had moved to a greater depth. Once plant growth had largely recovered (late July/ early August) the surface soil would become more attractive with new root growth and its accompyaning microflora and fauna.

5 i) Soil Biomass Carbon and Nitrogen

Return time was shorter in pasture and zerotill soil than that suggested in the literature. In one experiment, 2 mg C as glucose was added per gram of soil to four different soils. On average biomass was increased by 256 ug C/g soil 14 days after amendment (Sparling et al, 1981). Several possible explanations exist for this differer
The residue incorporated in the zerotill soil in this study was of poorer quality than that in pasture consisting of two year old corn trash, and one year old grain stalks which had already been weathered, leached and degraded by fungi and soil animals. In addition winter wheat plants were also added. However, in pasture soil the added residue was mostly growing plants including some legumes and therefore the biomass may have been stimulated more than that in zerotill resulting in a longer return time. The microbial biomass may not have been able to utilize this "poorer" residue as well as glucose and may have had to wait for "help" from the soil animals whose populations took longer to return. In addition measuring soil biomass includes all biomass, active

or not, and an increase in activity by certain microbes may not have been discernible.

The seasonal trend observed in pasture and zerotill soil in this study is similar to that found in other studies, biomass remaining relatively constant over time with some fluctuation (Patra et al, 1990). Higashida and Takao (1985) attributed these fluctuations to changes in the supply of substrates from the vegetation and that soil water status also controlled the appearance of these peaks. These results appear to agree with our results, biomass fluctuating in agreement with water content in our plots also.

ii) Soil biomass P

The variability of biomass P values is probably due to a problem with the method, or with lab technique. As the standard curve was acceptable, and the method did work on one sample date, the variability is probably due to technique. Phosphorus determination in water is very sensitive and this appears to be the downfall. For this reason and that the biomass P method requires much more effort, I recommend the ninhydrin-N method for determining soil biomass over this phosphorus method.

Srivastava and Singh (1988) reported a C:P ratio range in 0-10 cm soil of 9.0 for a teak plantation to 23.0 for corn cropland in India. Pasture soil C:P ratio (14.0) is well within this range (Table 8), but zerotill C:P is much lower at 5.8. This difference between pasture and zerotill may be due to a difference in plant dominance as crop type may effect C:P ratios. In two grasslands in India, C:P ratio varied from 14 to 19 when dominated by Heteropogon contortus and Imperata cylindrica respectively. Winter wheat with clover may promote a very low C:P ratio in the microbial biomass.

6. Emergence traps

Cultivation did not appear to have much effect on the emergent invertebrates. Return time using Method B was the first sampling date. The samples captured by the emergence traps were highly variable, sample variation being much greater than any consistent variation between plots. Individuals in the pupa or egg stage are well protected and are probably immune to the effects of cultivation. Emergent individuals in the larval form are small and mobile, so most would also probably avoid the effects of cultivation.

Similarity was lower for the pasture emergent community in unplowed-plowed than in unplowed-unplowed comparisons, where it was very close in zerotill soil. This is indirect evidence that the emergent community is more resilient in the zerotill soil than in pasture soil.

7. Litter decomposition rate

At 39 and 69 days after plowing, decomposition rate was higher in zerotill plowed soils than in pasture plowed soils. This difference is not due to differences in soil temperature or water content as these differences are small (Figures 15 and 16). A possible explanation for this difference is that the return times of decomposer animal populations are faster in zerotill soil. Soil biomass (Methods A and B), number of nematodes (A), and number of slugs and sowbugs (B and C) all returned faster in zerotill soil, and all are important in the decomposition process. It appears likely that the faster return of these invertebrates influenced decomposition rate.

In zerotill soils, decomposition rate was faster in plowed than in unplowed soil at 39 days at both depths. This is probably due to the stimulation of microbes and animals when the old residue and wheat was made available. Decomposition rate was greater on the surface of unplowed and plowed zerotill soil than at 10 cm (Table 10). This trend is likely a reflection of the dominance of fungi and surface feeding invertebrates in unplowed pasture and zerotill soils. Organisms in these soils are more adapted to feeding on surface residues, so decompocition rate is expected to be higher here. In unplowed pasture soil, decomposition rate was higher at 10 cm than at the surface. This may be due to the amount of residue at depth in the soil due to the dense plant growth and abundance of roots in the pasture soil. Organisms in the pasture soil are adapted to feeding on this organic matter and so are abundant at this depth.

8. Saturated hydraulic conductivity and bulk density

In pasture plots, dry bulk densities are similar in unplowed and plowed soil (Table 11). However, the saturated hydraulic conductivities are radically different (Table 12). These measurements indicate that although the amount of pore space is equal in the two soils, water flow through these pores is not. There must be a difference in pore continuity between these soils. Plowed pasture soil apppears to have greater pore continuity than its unplowed counterpart. This may be due to the dense root growth in the unplowed soil, the roots occupying pore space and limiting water flow.

In zerotill plots, dry bulk density and saturated hydraulic conductivity were significantly higher in unplowed soil (Tables 11 and 12). Pore space is less in the

unplowed soil but water flow is greater than in plowed zerotill soil. Pore continuity must be much higher in the unplowed zerotill soil perhaps because of intensive animal activity and limited root growth.

9. Water infiltration rate

It has been recommended to farmers that it is best to no-till the soil for four to five years and then plow it up and start over again. The information this study provides on infiltration rate and earthworm populations appears to contradict this recommendation. Earthworm populations do not appear to recover fully from plowing even after six months. In addition, plowing significantly reduces water infiltration rate compared to unplowed soil (Table 13) 100 days after plowing. These reductions are indicative of the long time required for biological activity to "peak". Zerotill soil takes many years to become optimal and this is reflected by the majority of research being performed in long term plots.

The descision to plow up zerotill fields is not supported by the "soil quality" indicators of infiltration rate, number of earthworms and pore continuity (previous section) in this study. This information must be balanced with other factors such as the need to incorporate raw manure into the soil. Chisel plowing or ridge tillage might be an acceptable intermediate.

10. Plant Dominance

In pasture soil, plant dominance was very similar before and after plowing. This

is because cultivation did not kill the dominant plant, grass. After cultivation, grass was able to grow back using its extensive root system.

In zerotill soil, the dominant plant winter wheat was killed by cultivation. Winter wheat went from 70% dominance in unplowed soil to 2% dominance in plowed soil. However, pigweed replaced winter wheat in the plowed soil, attaining 78% dominance. This is indicative of a momentum in zerotill soil. Herbicides are applied in agroecosystems to maintain dominance of the crop plant. In this case, atrazine was applied at 5 L/acre two years previously. When wheat was removed as the dominant plant, trazine resistant pigweed took its place, reaching even higher levels of dominance. As a result of this momentum, the system remains essentially unchanged.

Chapter 8 Discussion of Stability

Return times of population parameters were faster in zerotill soil with no exceptions (Tables 20 and 21). This conclusion allows rejection of the null hypothesis that there is no difference in return times between pasture and zerotill soil. Deflection of plowed population parameters away from ground state was significantly higher in pasture soil for number of nematodes, and abundance and eveness of cryptozoic invertebrates captured in pitfall traps (Table 2). Other population parameters had similar deflections in pasture and zerotill soil. The rate of return to ground state did not give consistent results for pasture or zerotill soil. Five population parameters had a faster rate of return in pasture soil, and four had a faster rate of return in zerotill soil (Table 3).

There are some differences between the pasture and zerotill soil in the size of their population parameters (Table 22). Of the 18 population parameters considered, nine were larger in pasture soil, one was larger in zerotill soil and 8 parameters were similar in both soils.

Diversity has been broken up into its two components, richness and eveness. Referring to Table 22, richness was greater in pasture for one community, and was the same in pasture and zerotill for two other communities. Eveness was similar in pasture and zerotill for two communities in which it was measured. Diversity appears to be similar or slightly greater in pasture than in the zerotill system.

The zerotill soil community appears to be more stable as defined by Hurd and

Table 20 Summary of return time results in pasture and zerotill when using Method A.

Population parameter	Return time (days) Pasture	Zerotill	Which System returned faster	Significance
Number of nematodes	73	41	Zerotill	<0.05
Abundance pitfall	102	46	Zerotill	n.s.
Richness pitfall	11	86	Pasture	n.s.
Eveness pitfall	156	38	Zerotill	<0.025
Number of slugs	did not return	120	Zerotill	<0.025
Number of sowbugs	did not return	did not return	-	-
Total no. of animals	did not return	did not return	-	-
Soil biomass 0-10cm	did not return	did not return	-	-
Soil biomass 10-20cm	46	24	Zerotill	<0.05
Soil biomass 0-20cm	54	23	Zerotill	<0.025

Table 21 Summary of return time results in pasture and zerotill when using Method B or C.

Population parameter	Return time (days) Pasture	Zerotill	Method	Which system returned faster
Number of nematodes	19	19	B	-
Number of slugs	57	2	C	Zerotill
Number of sowbugs	57	24	C	Zerotill
Total no. of animals	95	39	C	Zerotill
Soil biomass 0-10cm	9	2	B	Zerotill
Soil biomass 10-20cm	2	2	B	-
Soil biomass 0-20cm	2	2	B	-

Table 22 Differences between population parameters in zerotill and pasture soil.

Population Parameter	System parameter is larger in
Number of nematodes	Neither
Number of earthworms	Pasture
Mass of earthworms	Pasture
Abundance of cryptozoa	Zerotill
Richness of cryptozoa	Neither
Eveness of cryptozoa	Neither
Number of slugs	Neither
Number of sowbugs	Neither
Total number of animals(c.b.)	Pasture
Richness(cryptozoa boards)	Neither
Occurence of cryptozoa	Neither
Number of mites	Pasture
Total # of animals extracted	Pasture
Soil biomass 0-20 cm	Pasture
Em trap abundance	Pasture
Em trap richness	Pasture
Em trap eveness	Neither
Occurrence of emergent inverts.	Pasture

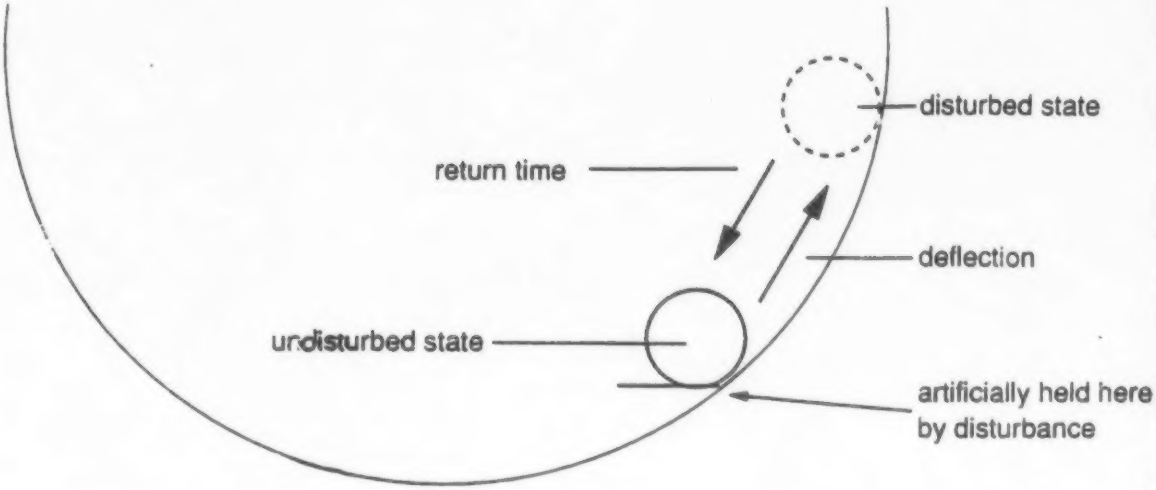
Wolf (1974) ,than the pasture community because the populations of organisms in the zerotill community are returning faster,and are deflected less from ground state. Three conceptual models involving disturbance may help to explain why the zerotill community is more stable than the pasture community.

The first model is a 'ball in a cup' model (Figure 17; similar to that of Begon et al., 1986). The ball represents the state of the community, and the cup is the limits to its movement. When the ball is displaced it should return to the same equilibrium. The pasture soil community is initially at a point of regional stability as it has not been disturbed for a long time (years). In contrast, the zerotill soil community is held at a point of local stability by continual agricultural disturbances. If the zerotill community is disturbed it will return to the point of local equilibrium. When the two communities are disturbed by the plowing and disking, the pasture community is displaced further from its equilibrium because it is not held at a point of local stability. The zerotill community therefore returns faster, as the disturbed state is closer to its equilibrium point.

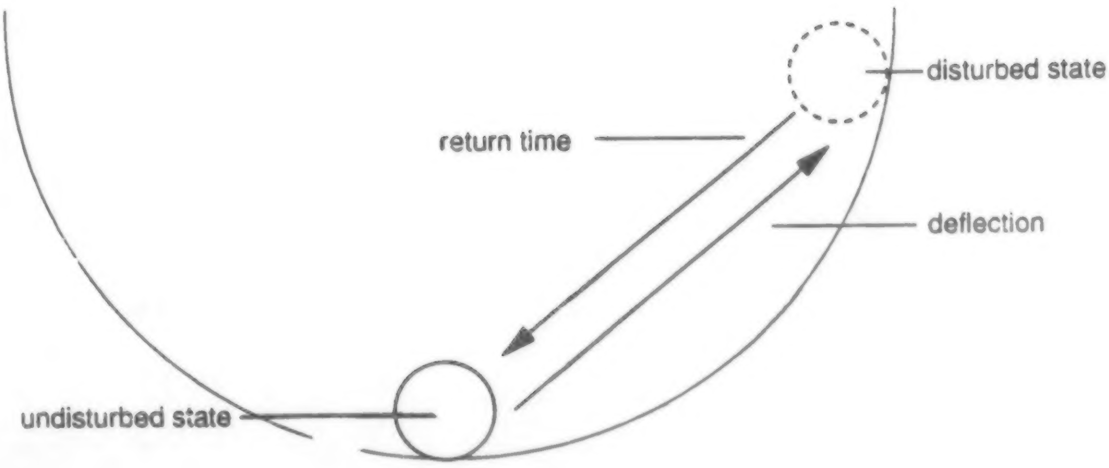
Evidence to support this conceptual model includes the following. There is evidence that the two systems start at different points in the cup. As stated previously, nine of 18 parameters were larger in pasture, and only one was larger in zerotill soil. There is also evidence that pasture population parameters are deflected further away from their equilibrium point. For the only three parameters whose difference in deflection was significantly different, all three had greater deflections in pasture soil. In addition, there is no consistent evidence that either system has a faster rate of return

Figure 17 Conceptual model of zerotill and pasture ecosystem stability.

Zerotill



Pasture



than the other.

Connell and Sousa (1983) also hypothesized that more disturbed communities may be more stable because the populations in the frequently disturbed community might colonize and grow so rapidly that they can recover completely between disturbances.

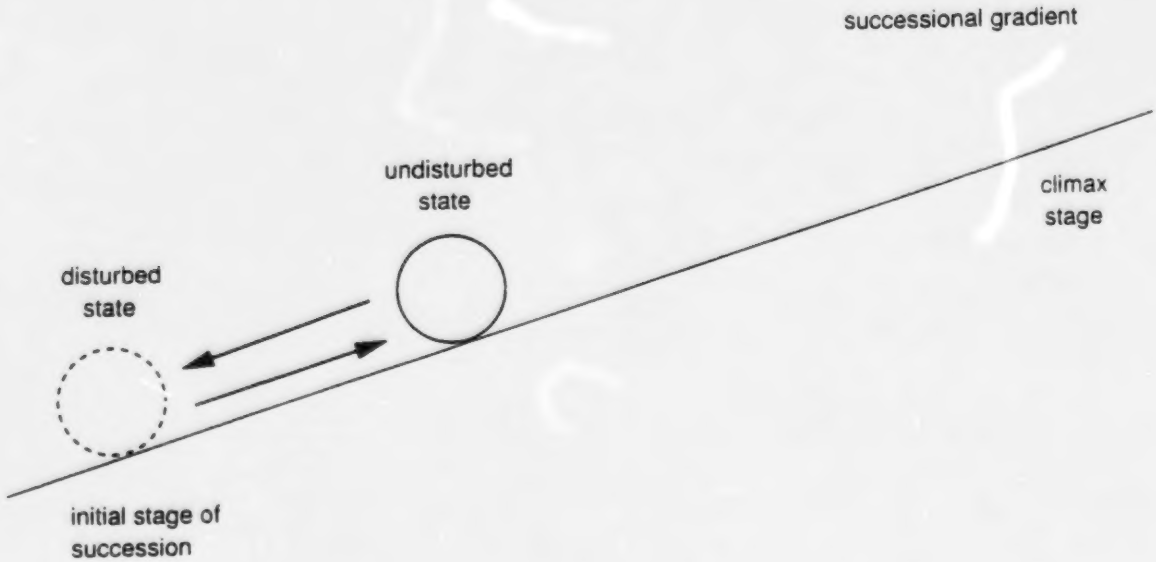
A study by Sohlenius (1989) also found that plowing had no long term effect on the nematode fauna and he hypothesized that the existing nematode fauna was selected to tolerate drastic disturbances. Both species abundance and diversity were able to recover relatively quickly.

The second model is similar to the first but it is related to succession. The pasture and zerotill systems are at different stages of succession (Figure 18). The pasture system has been undisturbed for five years and is starting to shift towards the local climax community of Maple and Eastern White pine. The zerotill community on the other h is constantly kept near the initial stage of succession by agricultural disturbance. Consequently when the communities are both knocked down nearer to the initial stage of succession by plowing, the pasture community has alot further to return to its ground (initial) state (Figure 18). The evidence provided to support the first model is also related to this model.

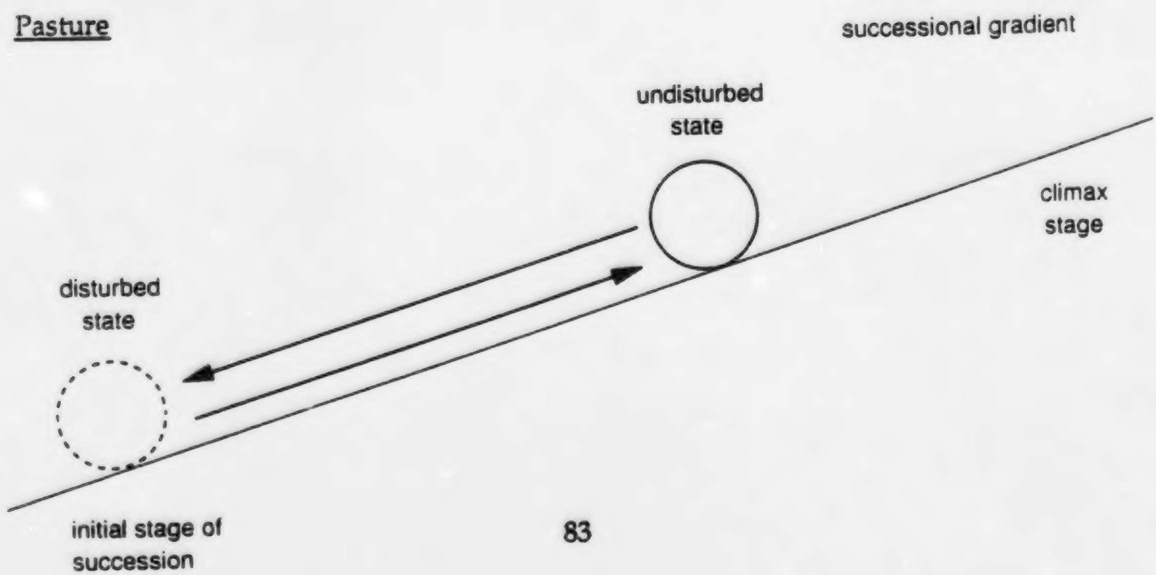
Succession has long been linked to stability, for example it has been assumed that succession generates diversity and that this diversity enhances ecosystem stability (Orians, 1975). However, diversity and stability are no longer strongly linked, so new theories have been developed. As succession progresses, fast-growing species are the

Figure 18 Conceptual model of succession and stability in natural and agro-ecosystems.

Zerotill



Pasture



first to develop, and these are gradually replaced with species with more interrelationships that have a slower turnover (Margalef, 1975). The perturbation of plowing and disking in this study has displaced both the pasture and zerotill systems to an earlier successional stage (McIntosh, 1980). Evidence exists that neither the zerotill or pasture system was displaced back to the original stage of succession. In both systems, it is apparent that parts of the communities have survived, for example the grass plants in the pasture system, so it appears that both systems would follow the same paths of succession that had brought them to their undisturbed state. The pasture system has had time to move through successional time than the zerotill system, so it is moved farther back in successional time than the zerotill system by the perturbation. This is supported by the greater deflections found in pasture. Since there appears to be no consistent difference in rate of return by either system to ground state it is understandable that return time is longer in the pasture system. This longer return time may in fact be due to the difference in the plants and animals present, the pasture having more complex relationships and slower turnover time.

This situation in plowed and unplowed soils is analagous to the lodgepole pine population of western Canada and the United States (Knight and Wallace, 1989). Lodgepole pine is serotinous, it has closed cones which open when the heat of fire breaks resin bonds allowing seed dispersal. However, not all lodgepole pines are serotinous: serotinous and nonserotinous trees usually coexist, with the relative abundance of each dependent on the last disturbance. If one were to start with equal numbers of serotinous and nonserotinous trees in a stand, in a few generations this stand

would change in composition. If there were fires in the stand, dominance would shift towards the serotinous type. If there were no fires in the stand, dominance would shift to the nonserotinous type. A fire at this point in the stand's history will have a varying effect depending on the stand's composition. If there were a fire in the nonserotinous stand, recovery from this disturbance should be very slow as the majority of cones would be of the nonserotinous type. This stand is analagous to the pasture community, neither being adapted to disturbance because they haven't experienced any in past years. If there were a fire in the serotinous stand, recovery would be faster and more complete, as the majority of cones would be serotinous and stimulated by fire. This stand is analagous to the zerotill community, both having experienced disturbance in the past.

There is no direct evidence from this study to support this model. There appears to be no difference (or very little) between the types of species found in zerotill and pasture soil. However, there may be differences within species between the two cropping systems, similar to the two varieties of lodgepole pine. This type of difference could contribute to the results found in this study. In addition, there may be differences in species in populations that were not examined closely, including the microbial biomass and the nematodes.

This theory is supported by the presence of; a permanent (autochthonous) microbial biomass which requires a small supply of energy for its survival and responds more slowly to added substrate, and a transient (zymogenous) microbial biomass promoted by the seasonal input of substrates and which will die out rapidly unless their energy demands are met. This is analagous to K and r strategists respectively, and any

successful microorganism will show characteristics of both strategies (Lynch, 1984). It is possible that in the pasture soil with such dense plant growth and long growing period that the autochthonous biomass does better where there is more root biomass (Lynch, 1984) and a more constant slow supply of substrate available via root exudates and decaying vegetation. Substrate availability should be more limited in agricultural ecosystems as plant growth is more limited to a certain time period, plant density is lower (usually) and some of the crop is harvested and removed from the field. This type of system might favor the zymogenous biomass which could respond to a more seasonal substrate availability.

With this difference in biomass domination, it is easy to see how a disturbance would effect each system differently. When plowed, the large zymogenous microbial biomass in the zerotill soil will respond quickly to the heavy substrate addition. When the pasture soil is plowed though, the autochthonous microbial biomass would not be able to respond to it, and it would take some time for the smaller zymogenous biomass of pasture soil to become effective. This difference would allow the zerotill system to return more quickly to ground state.

A relatively predictable environment (ie undisturbed) permits the evolution of a complex, fragile system. Certain basic themes tend to be selected as optimal. For example tropical trees and plants essentially all have the same reproductive strategy. In contrast, a very unpredictable environment requires a structurally simple system which favors the evolution of many alternate reproductive and annual regeneration strategies (May, 1975). Agroecosystems tend to be unpredictable, changes in crop,

herbicide use and fertilizer/manure application among others are continually occurring. As a result they tend to be more simple than adjacent undisturbed systems who continually evolve complex relationships. It is easier for the simple systems to recover from perturbation (May, 1975) and they are therefore more stable.

This study has shown that the zerotill system appears to be more stable than the pasture system. Diversity as broken down into richness and eveness is similar or slightly greater in the pasture system. There does not appear to be any simple relationship between diversity and stability on a gross scale in the two systems studied.

The results of this study indicate that agroecosystems are not always unstable monocultures. The zerotill system in this study appears more capable of recovering from disturbance than the pasture system, possibly because it is adapted to disturbance. This study, combined with the Suttman and Barrett (1979) study, casts serious doubts about instability in stressed ecosystems. Pest outbreaks, frequently associated with instability in agroecosystems may be due to managment caused instability of the pest populations, as was the case with the spruce budworms (Choristoneura fumifera), an introduced species. The spruce budworm outbreaks are part of a natural cycle in the forests of Eastern Canada. When foliage quality is high and weather conditions are ideal the growth rate of the spruce budworm increases and an outbreak results. In between outbreaks which occur every 30-50 years, low foliage quality and vertebrate predators keep budworm numbers low. Once a spray program is introduced to control budworms at epidemic levels, the cycle changes. Spraying reduces both budworm and vertebrate predator numbers, while keeping foliage quality high by limiting budworm damage.

In the following years, high foliage quality and low vertebrate predator number result in continued epidemic levels of budworms and this cycle generally continues as long as foliage outbreaks (Blais, 1974; Clark et al, 1979).

There are some interesting parallels between this forest-budworm system and agroecosystems. Foliage quality is artificially maintained at a high level, and predators of prey species are reduced by management practices in both systems. How similar these two systems are may be worth further study.

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APPENDIX I

Scientific and common names of organisms in this study:

Systematic list of the microflora and fauna found in pasture and zerotill soil, to the lowest level of identification.

Kingdom Monera

- Subkingdom Cyanobacteria - blue green algae
- Subkingdom Schizomycetes - bacteria

Kingdom Fungi

- Division Eumycophyta - true fungi
- Division Myxomycophyta - slime molds

Kingdom Animalia

- Phylum Nematoda - nematodes
- Phylum Mollusca
    - Class Gastropoda
        - Family Philomycidae - slugs
- Phylum Annelida
    - Class Oligochaeta
        - Family Lumbricidae - earthworms
        - Family Sparganophilidae - earthworms
- Phylum Arthropoda
    - Subphylum Chelicerata
        - Class Arachnida
            - Order Phalangida - harvestmen
            - Order Acarina - mites
                - Suborder Prostigmata
                - Suborder Mesostigmata
                - Suborder Cryptostigmata
            - Order Araneida - spiders
    - Subphylum Crustacea
        - Class Crustacea
            - Order Isopoda - sowbugs
    - Subphylum Urinamia
        - Class Chilopoda - centipedes
            - Order Lithobiomorpha
            - Order Geophilomorpha
        - Class Diplopoda - millipedes
            - Order Polydesmida - Scytonotus granulatus
            - Order Julida - Archiborioiulus pallidus
        - Class Insecta
            - Subclass Apterygota
                - Order Thysanura
                    - Family Campodeidae - diplurans
                - Order Collembola - springtails
                    - Family Sminthuridae
                    - Family Poduridae
                    - Family Entomobryinae

Subclass Pterygota
- Order Orthoptera
  - Family Acrididae - grasshopper
  - Family Gryllidae - crickets
- Order Pscoptera
- Order Thysanoptera - thrips
- Order Hemiptera
  - Family Nabidae - damsel bugs
  - Pentatomidae - stink bugs
- Order Homoptera
  - Family Cicadellidae - leafhoppers
  - Family Delphacidae - planthoppers
  - Family Ahpididae - aphids
- Order Coleoptera
  - Family Staphylinidae - rove beetles
  - Family Carabidae - carabid beetles
  - Family Silphidae - carrion beetles
  - Family Cantharidae - soldier beetles
  - Family Elateridae - click beetles
  - Family Nitidulidae - sap beetles
  - Family Coccinellidae - ladybird beetles
  - Family Curculionidae - snout beetles
  - Family Scarabaeidae - scarab beetles
- Order Lepidoptera - butterflies and moths
- Order Diptera
  - Family Mycetophilidae - fungus gnats
  - Family Sciaridae - dark winged fungus gnats
  - Family Empididae - dance flies
  - Family Phoridae - humpbacked flies
  - Family Syrphidae - bee flies
  - Family Calliphoridae - blow flies
  - Family Anthomyilidae
  - Family Drosophilidae
  - Family Pipinculidae
- Order Hymenoptera
  - Family Braconidae - parasitic wasps
  - Family Apidae - bees
  - Family Formicidae - ants

The Phylum and Class level of classification was taken from Villee, Solomon and Davis (1985). The Philomycidae classification is from Burch (1962), and the Lumbricidae and Sparganophilidae classification is from Reynolds (1977). Diplopoda classification was from Shelley (1988), and all other orders, suborders, and families were from the classification of Borror and Delong (1964).